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# ASPEN

SYMPOSIUM PROCEEDINGS

College of Forestry, University of Minnesota  
Minnesota Forest Industries Information Committee  
North Central Forest Experiment Station  
Forest Service, U. S. Department of Agriculture

## FOREWORD

The aspens — chiefly *Populus tremuloides* and *grandidentata* — are probably the most widespread hardwood timber species in Canada and the United States. Once looked upon as weed species in both countries, aspens are now recognized as valuable not only for timber products but also for wildlife food and cover and as essential to the esthetics of the North Country.

Aspen management and utilization are changing rapidly. Technology and experience have shown aspen to be extremely versatile: it can be managed intensively, it can be used for a variety of products, and it is adaptable to modern methods of harvest.

The Symposium speakers were purposely selected from a broad geographical base in Canada and the United States. The information they offer represents many years of research and experience by government agencies, universities, and private industry. We hope these papers will serve as a base upon which further progress will be built.

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# ASPEN: SYMPOSIUM PROCEEDINGS

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# SOME PROBLEMS AND ISSUES IN MANAGING THE ASPEN RESOURCE

John R. McGuire, *Chief*  
*USDA Forest Service*  
*Washington, D.C.*

I am happy to be here with you in Duluth, in the heart of our beautiful North Country. I am particularly pleased to have our Canadian associates join us to discuss ways to increase the production and improve the use of aspen, one of our most versatile hardwood trees. And, of course, it is fitting that we should meet here in the Lake States where aspen plays a key role in providing raw material for industry and jobs for local residents. This region is also noted for its wildlife and recreation resources, and aspen contributes significantly to the support of these resources. In this short meeting, we will be unable to discuss the management and use of aspen over its entire range, but much of what we learn here will also apply to aspen where it occurs elsewhere in Canada and the United States.

This symposium is one of several held in recent years to bring together the expertise on how to best manage and utilize some of our important tree species. By reporting here what has been learned about aspen through research and practical experience, we hope we can help each other to accelerate progress in solving many of the remaining problems of managing this valuable species.

We share a common objective: to improve and stabilize the economic status of those people who depend on the northern forests for all or part of their living. At the same time we must satisfy the needs of the general public for other forest values.

I am pleased with the broad scope of the program for this meeting. We will find out how much aspen is available and where it is located. We will learn the results of many years of research and experience in growing and utilizing aspen—from the establishment of new stands through the harvesting of mature stands and the conversion of aspen wood to usable products. We will be brought up to date on the latest logging techniques and new opportunities in utilization. And we will find out how to best manage aspen for wildlife habitat.

But, as managers and users of the aspen forest resource, we must recognize the increased public concern about how both private and public forest land is managed. We must be able to evaluate the impact of our management and timber harvesting practices on the total environment and find how to minimize these impacts. How and where we harvest forest products will always be strongly influenced by economics, but scenic and recreation values must receive proper weight in decision-making. Although it will be impossible to satisfy everyone's desires, I believe we can steer a course that will in the long run benefit most of our clients. This symposium should give us some direction for doing this.

National timber needs are steadily increasing. We already have exceeded the consumption rates predicted in 1962. The use of aspen by forest industries has increased steadily over the past three decades. Aspen now provides half the roundwood used by the pulp and paper industry in the Lake States. This use will increase. Recently-adopted grading rules are expected to result in expanded use of aspen by the housing industry. The aspen resource will play a major role in the future development of the forest industries in the Lake States.

The area of aspen type is declining, primarily because of ecological succession. However, the volume per acre and the resulting total supply of aspen growing stock is increasing in the Lake States. Overall, the aspen resource is adequate to satisfy the needs of an expanding industry for at least the next two decades. Local shortages could force industry to change procurement patterns and harvesting techniques in order to maintain an adequate wood supply. The total aspen resource picture is favorable, but how much of this resource will be available to industry is unknown.

The aspen resource is generally producing far below its potential. If we can do a better and more intensive job of management, aspen will provide an even greater share of the national timber needs in the decades to come.

Regardless of our needs for wood, however, we must not overlook the tremendous demands that are being made on forest land for other purposes. This region is blessed with cool summers, abundant lakes and streams, and extensive forests. Skiing, hunting, and fishing attract many visitors. Many come here just to relax in the forests. Forest landowners — and especially public landowners — are under constant and increasing pressure to provide more and better recreation opportunities.

How can we provide adequate timber products while maintaining an acceptable forest environment for the many people who come here to see and enjoy the forests and lakes? How can we increase or even maintain a variety of game for the hunter to harvest and for others to admire? How can we do all these things and also improve the economic status of the rural communities?

We are gathered here to consider these and related problems. Fortunately, some guidelines are already well established. First, we must intensify efforts to develop and improve the productive capacity of the aspen resource.

Second, we must do a better job of aspen management. We must manage each aspen stand and site combination to get maximum benefits from this resource. At the same time, we must minimize adverse impacts on esthetic and other values. Aspen management will require more skill and finesse than we have used in the past.

Third, we must be prepared to modify our timber management practices where necessary to create the conditions needed for wildlife habitat and other special values. For example, where deer and grouse populations need to be increased, we

need to plan and coordinate aspen harvests so the necessary food and habitat conditions are provided over large areas.

Fourth, we must do a better job of educating the public about the need for our aspen harvesting practices. These will be more acceptable to the viewing public once people understand that clearcutting is an essential part of aspen management. We can minimize disturbances and reduce their esthetic impact by more judicious arrangement and location of our harvest tracts. I am confident that both public and private land managers can do a better job in this respect.

And finally, we must improve utilization standards. Too much usable material is still left in the woods. Pulp yields and quality can be increased through improved technology. Profit margins might be increased by sorting aspen raw material for its highest use—veneer, lumber, or pulpwood.

Within these guidelines, we must provide managers with workable alternatives so they can cope with the changing pressures on the forest resource. The task will not be easy, but it can and will be done.

During this symposium we will be reminded that aspen has many desirable characteristics from the forest manager's viewpoint. Its vigorous suckers make aspen easy to regenerate. It is so intolerant that rapid natural thinning and pruning occur. Volume growth is rapid over a short rotation. Industry can use the wood for pulp and paper products as well as for veneer and lumber. At all stages in their development, aspen stands furnish food and cover for wildlife. And the golden aspen leaves provide color and variety in our fall landscapes.

Geneticists have developed aspen trees that promise to be even faster growing and possibly more disease and insect resistant than the trees in most natural stands. When adequate supplies of these superior aspens are available, we will want to upgrade our present stands.

Recently our Forest Engineering Laboratory at Houghton, Michigan, has found better ways to separate the bark from aspen chips. Once a commercially feasible system is developed, we will be able to chip whole trees in the woods and significantly improve utilization of the aspen resource and the esthetics of harvested areas.

These pluses make our job a little easier, but in themselves they will not solve our problems. This symposium will bring us up to date on what we know about managing and using the aspen resource. I hope it will also pinpoint those areas needing further study so that researchers can get busy on these problems as soon as possible.

One last word. We all grant that aspen is an important component of our northern forest resources, but we must not lose sight of the fact that conifers and many other hardwoods are equally important. Together, they comprise one of the most valuable and heavily used resources in the world. As we focus our attention on aspen here, we must be mindful that aspen is only part of an ecological complex that will challenge our scientific and managerial talents.

# THE RESOURCE AND ITS POTENTIAL IN NORTH AMERICA

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**ABSTRACT.**—The United States and Canada have different problems with respect to the utilization of their aspen resources. In the United States, aspen is more highly concentrated and its use, particularly in pulping, is well established and increasing. The present cut of aspen is roughly 50 percent of allowable cut, and within 30 years the allowable cut will probably double; growth and use will be in close balance by the end of the century. This pattern of aspen use arises from the fact that in the regions where it is most abundant (Lake States) there is a diminishing supply of softwoods, and also a well-established and diverse pulp and paper industry. Compared with the United States, Canada has five times as much aspen and harvests less than half as much. Aspen resources are more widely spread; the cut is small and is not increasing appreciably. No change in this trend is anticipated in the near future. Even by the turn of the century, it is likely that less than half of Canada's annual allowable cut of aspen will be utilized. Present evidence points to the conclusion that most of the aspen in North America will be used for fiber products—pulp, paper, paperboard, fiberboard, and composition board. A mill complex utilizing aspen and softwoods is outlined.

The *Populus* genus in general and the *tremuloides* species in particular occupy a unique position among commercial woods. They are among the most widely distributed, they grow on a wide range of sites, and under favorable conditions, they can be extremely fast growing (Bella and Jarvis 1967). They are particularly susceptible to a host of diseases and predators (Graham *et al.* 1963), and compared with many species, they are rather short-lived. In many areas, they have been considered to be an undesirable weed species; in other areas, they are considered among the more desirable of plantation species. Although they represent only a small fraction of total forest stock [7 percent in North America (table 1), 2 percent in the Soviet Union (Tseplyaev 1965)], their anomalous position generally, and the extent to which they represent problems and opportunities in growth and utilization, is indicated by the fact that there is more technical literature relating to *Populus* species than to any other wood. A number of comprehensive bibliographies (Brown *et al.* 1957, Roth and Weiner 1964, Farmer and McKnight 1967, Shoup *et al.* 1968, Pronin and Vaughan 1967) and

reviews (Lamb 1967, Maini and Cayford 1968) on aspen<sup>1</sup> have been published.

Table 1. — *Forest resources of the United States and Canada*  
(In million cubic meters)

Country	Total	Softwoods	Hardwoods	Aspen
United States <sup>1/</sup>	19,800	13,100	6,700	(2/) <sup>46</sup>
Canada <sup>3/</sup>	21,200	17,200	4,000	(2/) <sup>2,300</sup>

1/ Net volume of timber on commercial forest lands.

Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 150, 159, 160. 1965.

2/ Aspen plus cottonwood. The most recent value obtained from the U.S. Dep. Agr. is 500 million cubic meters.

3/ Merchantable volume. Taken from: Can. Dominion Bur. Statist. Canadian forestry statistics, 1963 and 1964, Cat. 25-202, Ottawa, Ont. p. 7. 1967.

4/ *Populus* spp., mainly *P. tremuloides*.

<sup>1</sup> Unless otherwise specified, in the balance of this paper the single name "aspen" refers to "aspen plus cottonwood" for United States data and to "*Populus* spp., mainly *P. tremuloides* Michx." for Canadian data.

The purpose of the present report is to broadly review *Populus* in North America in terms of resources and utilization, and to indicate probable trends in growth and utilization over the next three decades.

## TOTAL GROWING STOCK — PRESENT

### General

The relative position of aspen to other wood resources is shown in table 1, which gives the total wood resources of the United States and Canada.

It will be noted that hardwood growing stock is much greater in the United States than in Canada, whereas the growing stock of aspen is much greater in Canada.

### Distribution

#### in the United States and Canada

In the United States, 63 percent of the total aspen reserves are in the East (table 2); the bulk of aspen is concentrated in the Lake States and Colorado (table 3). In 1964, the aspen cut in the Lake States for pulp was 3.56 million cubic meters and the total aspen cut was 5.0 million cubic meters (Lamb 1967).

In Canada, the largest volumes of aspen are found in Ontario, British Columbia and Alberta (table 4).

## TOTAL GROWING STOCK — FUTURE

### United States

Projections for hardwood timber growth in the United States are given in table 5. No detailed analysis was found for inventory changes in the total aspen resources in the United States. However, individual studies (Stone 1961, Chase 1968) indicate that the area of aspen forest, and the aspen growing stock, have increased substantially over the past 40 years, and would be expected to continue increasing (Quinney 1961, Groff 1966). It is assumed, optimistically, that the growing stock of aspen will show no less than the 3 percent uncompounded increase indicated for hardwoods generally in table 5. In the United States, the basic problem of aspen utilization is one of economics rather than developing new ways to utilize the species. There is sufficient aspen at present to warrant, say, twice the present cut, but the present cut is limited by the fact that there is not a sufficient

Table 2.—*Net volume of timber in the United States*<sup>1</sup>

Species	: Million cubic meters
Eastern softwoods	2,800
Eastern hardwoods	6,100
Eastern aspen <sup>2/</sup>	290
Western softwoods	10,300
Western hardwoods	600
Western aspen <sup>2/</sup>	170

1/ Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 149, 150, 159, 160. 1965.

2/ Aspen plus cottonwood.

Table 3.—*Net volume of aspen*<sup>1</sup> *in the United States*<sup>2</sup>  
(In million cubic meters)

Region	: Total hardwoods	: Aspen	: Percent of total aspen
New England States	500	25	5.4
Mid-Atlantic States	1,290	27	5.8
Lake States	780	208	45.0
Central States	880	22	4.7
Colorado	102	69	15.0
Total	6,700	460	100.0

1/ Aspen plus cottonwood.

2/ Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 149, 150, 159, 160. 1965.

Table 4.—*Net merchantable volume of aspen*<sup>1</sup> *in Canada*<sup>2</sup>  
(In million cubic meters)

Region	: Total hardwoods	: Aspen	: Percent of total aspen
Ontario	1,020	496	27
Alberta	470	470	25
British Columbia	550	397	21
Saskatchewan	286	246	13
Total	3,400	1,860	100

1/ *Populus* spp., mainly *P. tremuloides*.

2/ Taken from: Maini, J. S., and J. H. Cayford (editors). Growth and utilization of poplars in Canada. Can. Dep. For. Rural Dev. Publ. 1205: p. 219. 1968.

Table 5. — *Estimate of future growing stock, growth and cut of hardwoods in the United States<sup>1</sup>*  
(In million cubic meters)

Year	Growing stock	Growth <sup>2</sup>	Cut
1952	4,700	187	94
1962	5,500	207	82
1970	6,200	207	99
1980	7,100	198	122
1990	7,700	181	156
2000	7,600	181	204

1/ Taken from: USDA Forest Service. Timber trends in the United States. Resour Rep. 17: p. 132. 1965.

2/ Net annual growth plus ingrowth.

supply of quality logs at competitive prices to warrant exploitation.

The above assumption that the growing stock of aspen will double within the next 30 years assumes some application of new logging, silvicultural, and utilization practices. It is reasonable that application of new harvesting techniques (Paper Trade Journal 1971), the harvesting of smaller diameter trees (Keays 1970a, p. 25), shorter rotations (Keays 1970a, p. 24) and the utilization of puckerbrush<sup>2</sup> would increase the volume of aspen available for use. The problem is one common to most projection analyses — to distinguish between what might be done and what actually will be done (see pages 10-15).

## Canada

The same general principles discussed above are applicable to aspen growing stock and use in Canada. The area of aspen forest will probably increase somewhat, particularly as the result of a retreat from uneconomical farm lands; the use of smaller diameter trees and shorter rotations (Bella and Jarvis 1967) would give appreciably more aspen than the 2,300 million cubic meters considered as growing stock at the present time. As discussed below, the serious problems in Canada are to find ways to utilize a larger part of the aspen already growing, and more particularly, to develop new concepts of aspen utilization.

## PRESENT UTILIZATION

As evidenced by the world literature, aspen can be used for a large number of end products. Table 6 gives the broad categories of aspen use in Canada.

Table 6. — *Use of aspen in Canada<sup>1</sup>, yearly average, 1961-1965*

Distribution	Million cubic meters
Allowable annual cut	41.00
Actual annual cut	2.14
Pulpwood	1.24
Plywood	.28
Composition board	.25
Sawmills	.14
Exports	.23

1/ Taken from: Maini, J. S., and J. H. Cayford (editors). 1968. Growth and utilization of poplars in Canada. Can. Dep. For. Rural Dev., Publ. 1205: p. 233.

The general pattern of aspen use is much the same in the United States as in Canada, but the magnitude and trends of use have been different. In Canada, pulpwood accounts for 60 percent of aspen use. In the Lake States, pulpwood use is a higher percentage of total aspen use (Lamb 1967). However, where there has been a slight decrease in the use of aspen for pulpwood in recent years in Canada (Clayton 1968), there has been a fairly steady increase in the use of aspen in the Lake States pulp mills (table 7).

## FUTURE UTILIZATION

### United States

It is expected that aspen use in the United States will follow much the same patterns as in the past. The use of aspen for many solid products (Vaughan 1965) will show a moderate increase. Growth in the use of aspen for solid products will be limited by competitive products, markets, and particularly by a limited supply of high-quality peeler and saw logs.

Much of the increased aspen cut will be used for fiber products—fiberboard, composition board and pulp. Table 8 gives an estimate of future pulpwood production in the United States.

<sup>2</sup> Young, H. E. Personal communication.

Table 7.—*Aspen pulpwood production in the Lake States*

Year	Million cubic meters	Percent of total pulpwood cut
1930 <sup>1/</sup>	0.14	4
1940 <sup>1/</sup>	.37	9
1950 <sup>2/</sup>	1.5	37
1960 <sup>3/</sup>	3.4	48
1969 <sup>4/</sup>	4.1	50

<sup>1/</sup> Taken from: Pulpwood stands, procurement and utilization. 1947. Tappi Monogr. 4, New York. p. 50.

<sup>2/</sup> Taken from: Horn, A. G. 1952. Ten years' pulpwood production in the Lake States (1942-1951). USDA Forest Serv. Tech. Note 384, 2 p. Lake States Forest Exp. Sta., St. Paul, Minn.

<sup>3/</sup> Taken from: Horn, A. G. 1961. Lake States pulpwood production up 11 percent in 1960. USDA Forest Serv. Tech. Note 606, 2 p. Lake States Forest Exp. Sta., St. Paul, Minn.

<sup>4/</sup> Taken from: Blyth, James E. 1970. Lake States pulpwood production rises 11 percent in 1969. USDA Forest Serv. Res. Note NC-100, 3 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.

Table 8.—*Production of roundwood pulpwood in the United States*  
(In million cubic meters)

Year	Softwoods	Hardwoods
1960 <sup>1/</sup>	55.5	17.5
1970 <sup>1/</sup>	76.1	34.4
1980 <sup>1/</sup>	121.0	59.2
1985 <sup>1/</sup>	146.0	73.9
1990 <sup>2/</sup>	<sup>3/</sup> (167.0)	(90.0)
2000 <sup>2/</sup>	(210.0)	(120.0)

<sup>1/</sup> Taken from: Hair, D. Use of regression equations for projecting trends in demand for paper and paperboard. USDA For. Serv. Resour. Rep. 18: p. 53. 1967.

<sup>2/</sup> Taken from: USDA Forest Service. Timber trends in the United States. Resour. Rep. 17: p. 70. 1965.

<sup>3/</sup> The numbers in parentheses represent projections of Dwight Hair's 1985 estimates.

Increased use of aspen in pulping would be expected to parallel increased use of hardwoods generally, and the next 30 years should see a fourfold increase in the use of aspen for fiber products.

## Canada

In Canada, no more than a modest increase in the use of aspen for solid products or for pulpwood is

expected in the near future (Canada Department of Forestry and Rural Development 1968). In spite of vast aspen reserves, there is a limited supply of quality logs that can be extracted and processed economically. At the present rate of expanded aspen use, the total use in Canada might reach 10 to 15 percent of the annual allowable cut within 15 years. Realization of any large part of the aspen potential will have to involve new patterns of use. One example would be large-scale use of aspen for light framing lumber. Another example, inclusion of steamed aspen in standard diets for ruminants (Bender *et al.* 1970), is undergoing extensive trials (Heaney and Bender 1970).<sup>3</sup> Initial results indicate a potentially new use for aspen, but the quantity of aspen that might be thus consumed is difficult to predict. A third possibility is increased use of aspen for furniture stock, which is under active study by the Eastern Forest Products Laboratory, the Manitoba Department of Industry and Commerce, and the Canadian Department of Industry, Trade and Commerce.

With present knowledge, it is difficult to guess when these new Canadian use patterns might evolve. Most of the recent expansion in pulp production has involved use of preferred softwood species, particularly in British Columbia (British Columbia Hydro and Power Authority 1966). There are still reserves of preferred softwoods in British Columbia, the prairie provinces, and in eastern Canada, and it is reasonable that these resources will be used prior to any massive expansion in aspen use. This trend may be modified by government policy necessitating increased aspen cut. Large-scale use of softwoods in the prairie provinces may be delayed because of distance from markets and other adverse economic factors.

At some time between now and the year 2000, probably between 1980 and 1990, the world demand for fiber products (Keays 1970b, Solomko 1970) combined with unavailability of softwoods will lead to the exploitation of Canadian aspen resources. It is likely that there will be an interim period when existing pulp mills will use more aspen, and there will be increased pressure for the use of aspen by mills not presently doing so.

<sup>3</sup> Bender, F. Personal communication.

A number of developments can be expected in this quantum-jump increase in the use of Canada's aspen resources: (1) The development of large, integrated complexes combining plywood, lumber, veneer, dimension stock, and fiber products; (2) the use of large amounts of aspen in kraft pulping for fine papers; (3) the development of a pulp suitable for high-quality newsprint, probably with no more than a small addition of softwood pulps, by chemical treatment of aspen, followed by refining and by brightening or a mild bleaching step; and (4) the manufacture of fine papers from pulp mixtures of mature softwoods and hardwoods.

A suggestion for a future mill complex, or an extension of the complex suggested by Vaughan (1965) utilizing aspen and softwoods, is shown schematically in figure 1. Stream A involves manufacture of softwood bleached kraft pulp, which can be sold as such

or partly converted into newsprint. Stream B involves manufacture of aspen bleached kraft pulp and aspen chemigroundwood pulp (Richardson and LeMahieu 1965). The latter in admixture with softwood bleached kraft pulp could make up a newsprint furnish (Perry and Canty 1971). The remaining aspen bleached kraft pulp could either be sold as such or used with softwood bleached kraft pulp to manufacture a variety of fine papers.

## SUMMARY

The aspen resource and its uses in the United States and Canada are summarized in table 9. It is apparent that the two countries have different aspen utilization problems. In the United States, aspen is more highly concentrated and the use of aspen, particularly in pulping, is well established and increasing. The present cut of aspen is roughly 50 percent

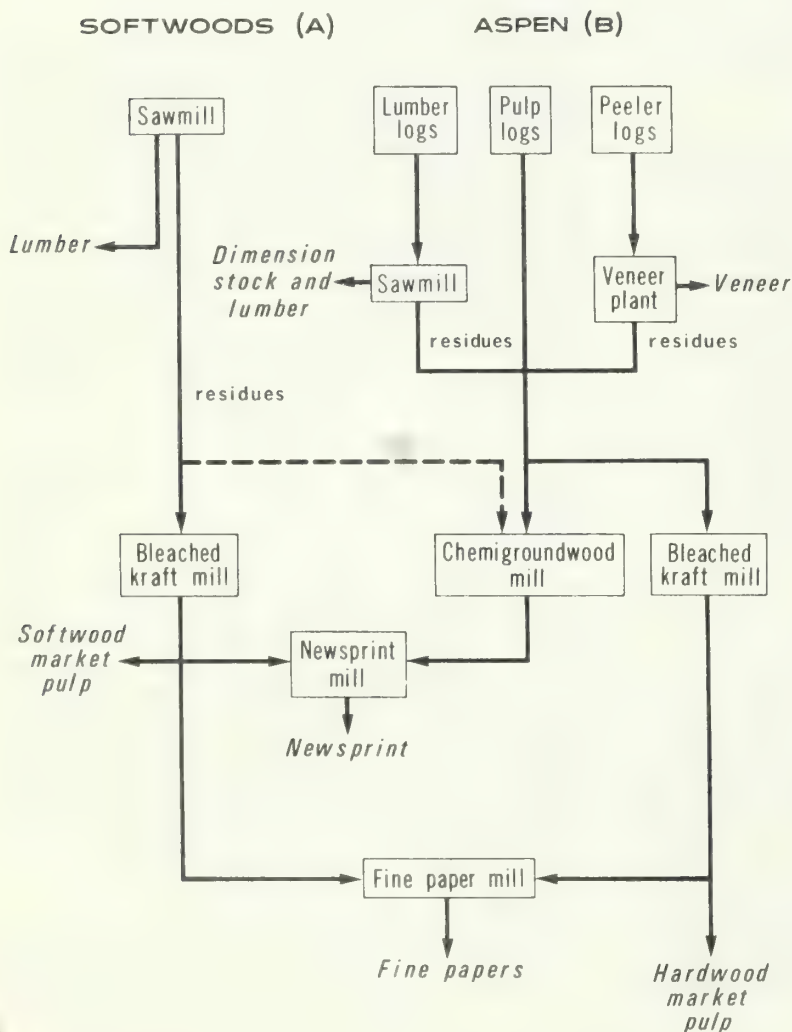


Figure 1. — Schematic diagram of proposed softwood-aspen pulp mill complex.

of allowable cut, and within 30 years, the allowable cut will probably double; growth and use will be in close balance by the end of the century. This paper of aspen use arises from the fact that in regions where aspen is most abundant (Lake States), there is a diminishing supply of softwoods and a well-established and diverse pulp and paper industry.

Table 9. — *Estimate of future aspen resources and use*  
(In million cubic meters)

Period	: Timber : : volume :	Allowable : annual cut :	Actual : annual cut
<u>United States</u>			
Present	460	9	4
In 15 years	>700	14	10
In 30 years	>900	18	18
<u>Canada</u>			
Present	2,300	46	2
In 15 years	>3,000	60	6
In 30 years	>3,500	70	25

Compared with the United States, Canada has five times as much aspen and exploits less than half as much. Aspen resources are more widely spread; the aspen cut is small and is not increasing appreciably. No change in this trend is anticipated in the near future. Even by the turn of the century, it is likely that less than half of Canada's annual allowable cut of aspen will be utilized. All evidence points to the conclusion that most of the aspen in North America will be used for fiber products — pulp, paper, paperboard, fiberboard, and composition board.

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# PROJECTIONS OF INVENTORIES IN THE LAKE STATES<sup>1</sup>

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**ABSTRACT.**—Today's apparent aspen surplus cannot continue indefinitely in all regions if the historical trends of cut, growth, and utilization continue. The greatest potential difficulties lie in northeastern Wisconsin and Michigan — the brightest outlook is in Minnesota.

In 1970 nearly two million cords of aspen pulpwood were cut in Michigan, Minnesota, and Wisconsin. This cut was about 50 percent of the roundwood pulpwood harvested in the region. The results of a recent study indicate that in parts of Wisconsin and Michigan recent cutting trends cannot be sustained in the future.

The study had two objectives. The first was to provide a common source of inventory data for aspen by describing the current status of the growing stock in a base year for all survey units in the study.<sup>3</sup> The second objective was to project to the year 2000 future levels of cut and growing stock under several sets of likely conditions. The present paper will discuss only the second objective.

The full results of the original study and the details of the projection procedure will be published soon by the North Central Forest Experiment Station as

a research paper. Individuals making serious use of the results are urged to obtain this paper because a summary as presented here cannot give sufficient background and details.

## FUTURE RESOURCE CONDITIONS

Projections were limited to three sets of conditions that were judged generally indicative of what could happen to the resource. The sets of conditions, or assumptions, were called *recent trends*, *breakup*, and *positive practices* and were used to project cut and growing stock in each survey unit.

The *recent trends* projections show what the cut and growing stock would be if trends which prevailed in the last decade or so continued into the future. They are derived from changes between the last two forest surveys or from recent historical trends. These projections can act as a standard of comparison and may indicate whether or not we should change our current practices.

Aspen trees begin to deteriorate rapidly after they reach maturity, a process commonly called "breakup." Although most foresters agree breakup occurs, there is a difference of opinion about the amount now and in the future. Unfortunately, field data to answer these questions are not readily available. The *breakup* condition simulates widespread breakup occurring immediately thereby projecting a minimum or "worst-likely" condition.

Land managers' actions could diminish breakup or

<sup>1</sup> This paper summarizes the results reported in Leuschner, William A., *Present and future aspen inventories in the Lake States*. (Manuscript in preparation.)

<sup>2</sup> The author was Economist, North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minnesota, at the time this paper was written.

<sup>3</sup> Survey units in the study were Michigan's Eastern and Western Upper Peninsula and Northern Lower Peninsula; Minnesota's Lake Superior, Central Pine, and Rainy River; and Wisconsin's Northeast, Northwest, and Central units.

change recent trends. Some actions will usually have an additive or positive effect on the level of aspen growing stock. The *positive practices* assumptions indicate what these actions could accomplish if they were instituted today — they are NOT a prescription of what should be done to increase the volume of aspen resource in the Lake States.

## REGIONAL PROJECTIONS

Goods and services, including harvested aspen, flow within and sometimes between economic regions. Three regions were identified for use in this study: (1) the three northernmost survey units in Minnesota, (2) the northern three survey units in Wisconsin and the two units in Michigan's Upper Peninsula (U.P.), and (3) the Northern Lower Peninsula survey unit in Michigan. These three regions were projected separately which meant the units within any one region could interact with each other but not with the units in other regions.

Before discussing the results it should be mentioned that these are projections, not predictions. Although they give an exact amount of inventory or cut at a precise point in time, they really indicate the general level and approximate timing within the bounds of the assumptions.

The reader should be careful to understand the assumptions before making major decisions based upon the projections. He should not interpret the projections too literally, and he should remember that land managers can change conditions and hence results. Although the projections are qualified and should be made anew every few years, they are, nonetheless, useful tools.

### Minnesota

The Minnesota region has the weakest data base, due in part to the data's age and in part to the inaccessibility of cooperator data. The results for this region must therefore be considered the least reliable for the three regions.

Regardless of the set of assumptions used the inventory is sufficient to sustain the projected cut in each of the units over the entire period of the projections. If *recent trends* continue there is a sizeable increase in growing stock in every survey unit, and even under

the *breakup* assumptions most units maintain their inventory levels. The *positive practices* projections generally show a redistribution of inventory to more realistic levels and the advantage, if any, is in improved volume distribution by diameter (fig. 1).

## Wisconsin and Michigan's Upper Peninsula

Five survey units in Wisconsin and Michigan's U.P. were allowed to interact for this set of projections. The *recent trends* and *breakup* projections show that in 15 to 25 years northeast Wisconsin and the U.P. will not be able to support their projected cut.

Further, all the timber cut from these areas after the cut is diminished is projected in the 6- and 8-inch d.b.h. classes. However, if industry will take this small diameter stock the region as a whole can support the projected cut until about 1995 (fig. 2).

There is a rapid and steady decrease in growing stock inventories in the early years for those units with a diminished cut. The other units show varying degrees of increased growing stock, at least in the early years of the projections.

Under the *positive practices* assumptions each unit is able to support its projected cut. Essentially, the cut is shifted from those units which did not sustain it and is added to the other. Positive practices also project an increased proportion of volume in the larger diameter classes. The growing stock projections, while improved, still show a downward trend in most survey units.

### Michigan's Northern Lower Peninsula

In this region of only one survey unit, cut is maintained under both the *recent trends* and *positive practices* assumptions until the final years of the projections, while the *breakup* assumptions cause a diminished cut about five years earlier. Almost all the cut is in the 6- and 8-inch d.b.h. classes by the time it is diminished (a trend common by now) except under *positive practices* where only 70 percent is in these classes. In all projections the growing stock shows a sharp downward trend although the reallocation of cut under *positive practices* does not have its usual significance because there is only one unit in this region (fig. 3).

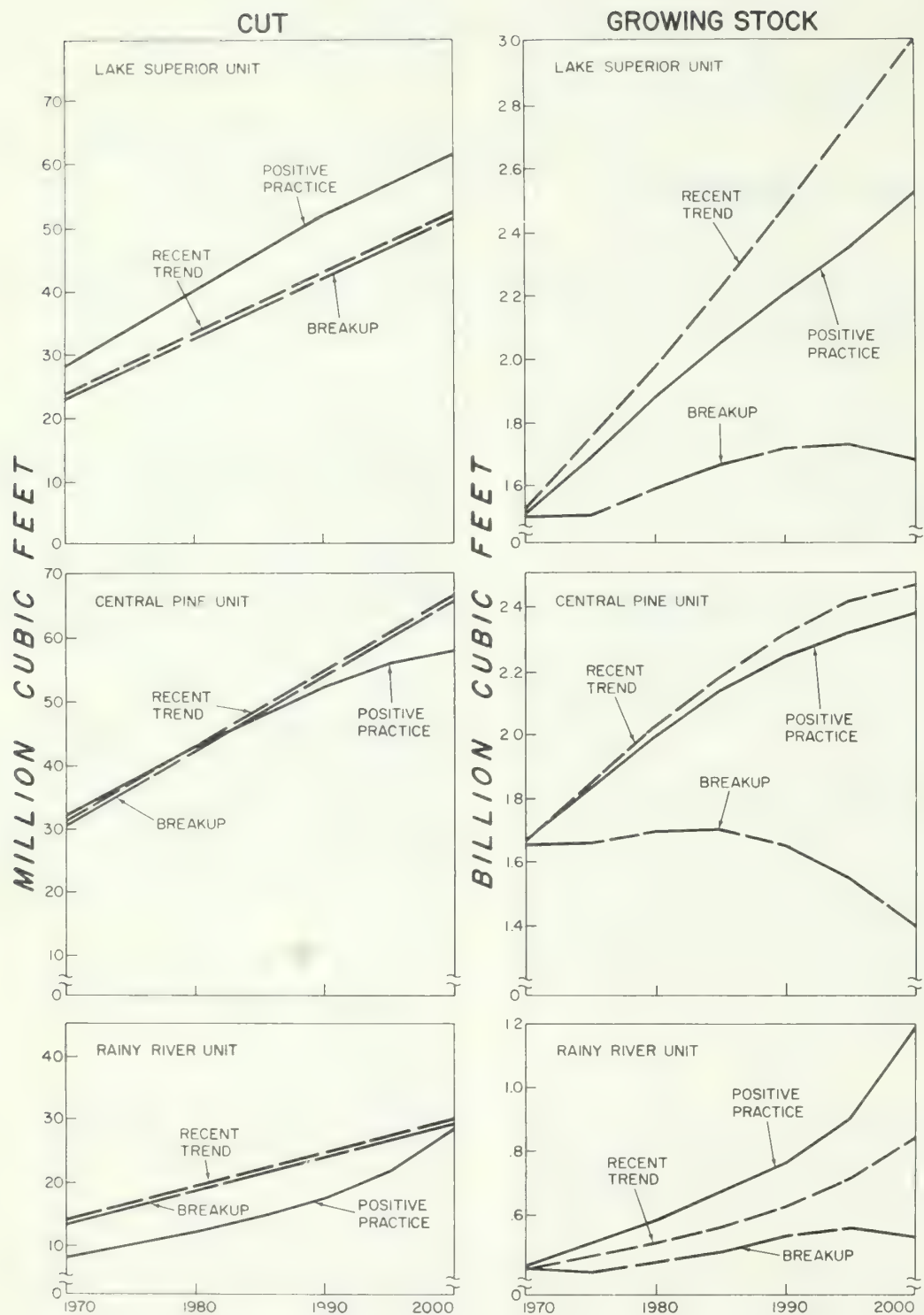


Figure 1. — Projections of cut and growing stock for Minnesota region, by assumption, 5-year average every 5 years.

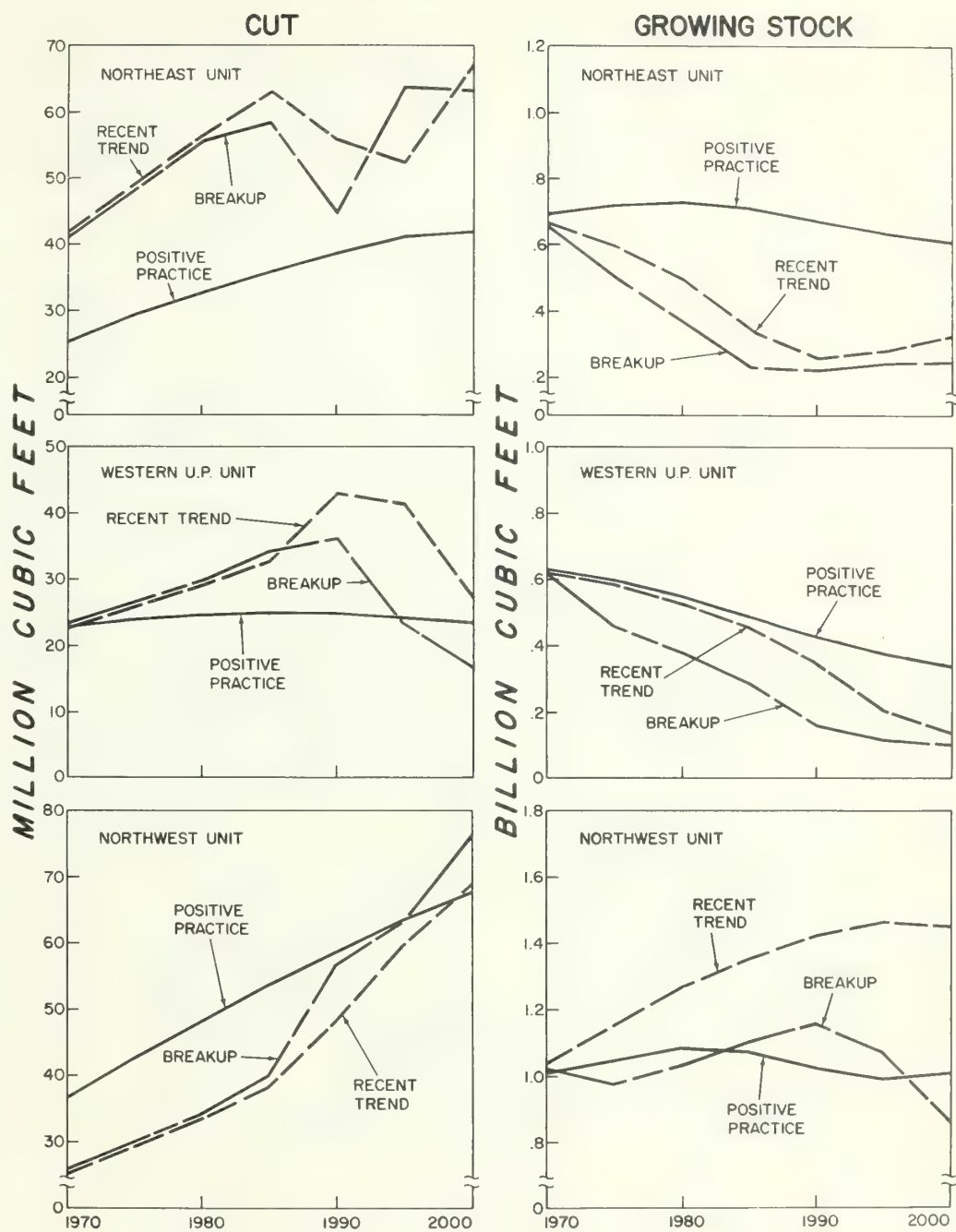


Figure 2.—Projections of cut and growing stock for Wisconsin and Michigan Upper Peninsula region, by assumption, 5-year average every 5 years.

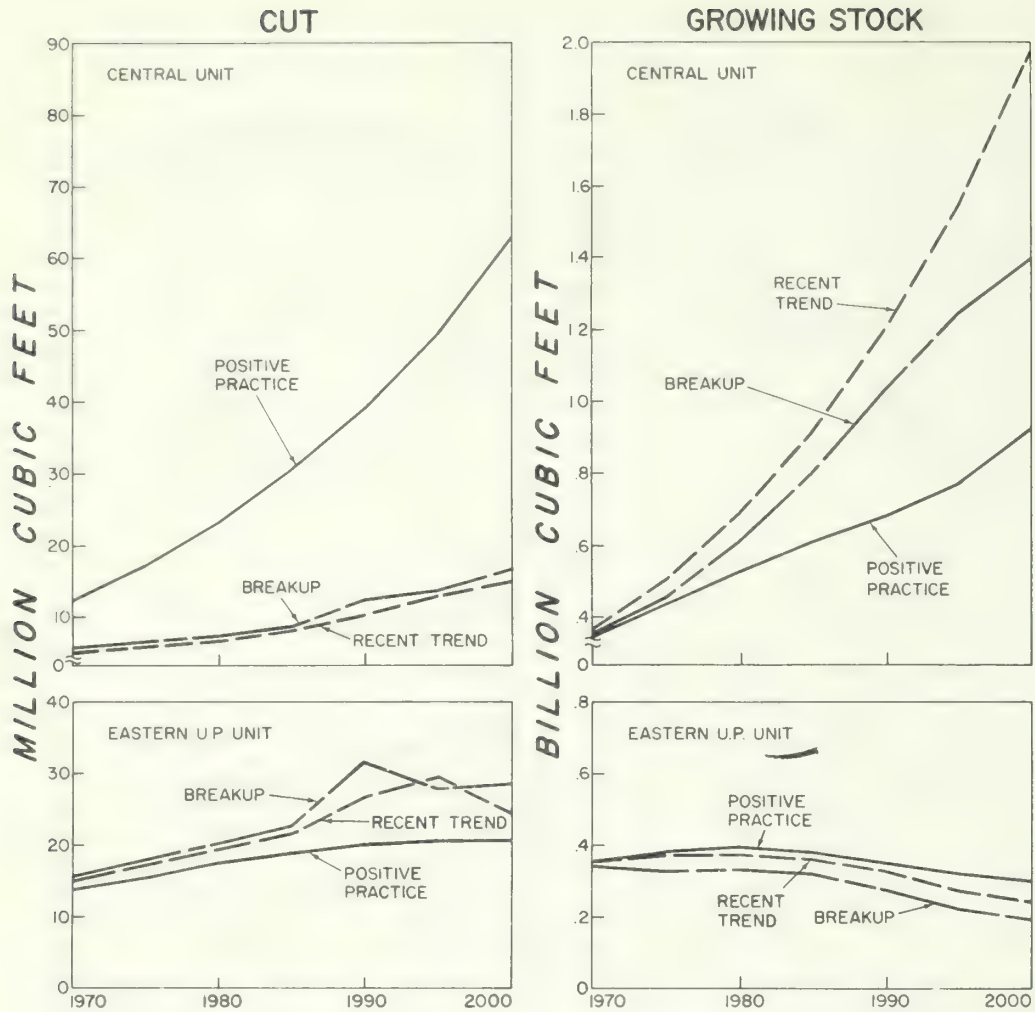


Figure 2. — (Continued)

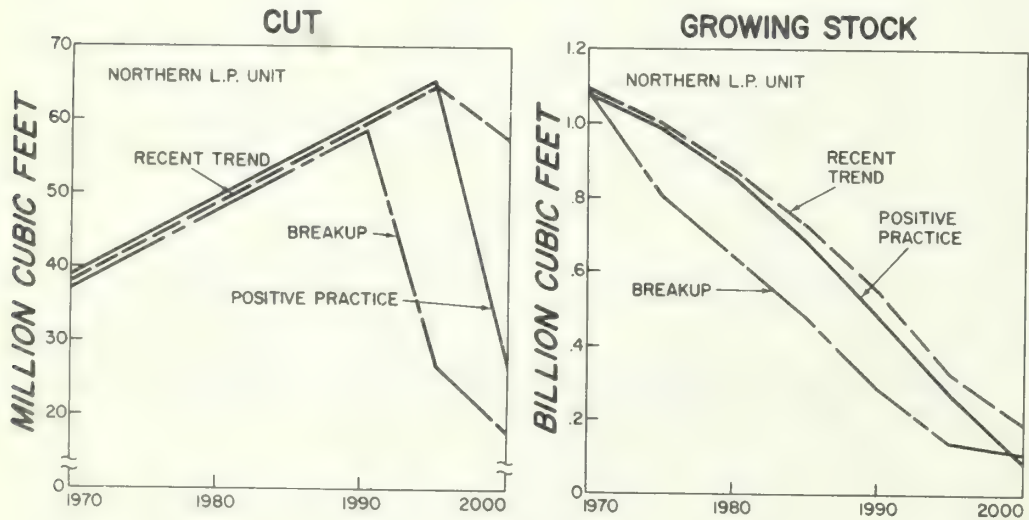


Figure 3. — Projections of cut and growing stock for Michigan Northern Lower Peninsula region, by assumption, 5-year average every 5 years.

## SUMMARY AND CONCLUSIONS

We cannot expect today's apparent surplus of aspen to continue indefinitely in all regions of the Lake States if the historical trends of cut, growth, and utilization continue into the future. The degree to which historical trends cannot be followed varies by geographical location.

The northernmost survey units in Wisconsin and all of Michigan's Upper Peninsula, show a generally unfavorable picture. The historical trend of cut is likely to be diminished in Wisconsin's Northeast unit in 15 to 20 years and in the U.P. in 20 to 25 years. In addition, almost all the cut in these units from the time it is diminished is projected in the 6- and 8-inch d.b.h. classes. With a few exceptions the growing stock projections show a generally deteriorating picture. However, the *positive practices* projections indicate each survey unit can support its reallocated cut and that the overall condition of the resource can be improved from what it would have been if historical trends had continued. These projections also show more cut and growing stock volume in the larger diameter classes.

The Northern Lower Peninsula survey unit supports its historical trend of cut during most of the projection period but at the expense of a constantly deteriorating resource.

The northernmost survey units in Minnesota have the brightest outlook. The projected cut is supported and the ending inventory is higher than present in all cases except the *breakup* projections in the Central Pine unit. The consistently higher inventory may indicate the region can support more than the projected cut.

Several conclusions can be drawn from these

projections. First, forest industries drawing their aspen from Michigan and Wisconsin must plan to procure their wood elsewhere within these States, substitute other species of wood for aspen, or cut less than the projected amount during the next 15 to 25 years. Further, firms planning replacement of their capital equipment would be wise where possible to install equipment and processes that can substitute other wood species for aspen at minimum cost.

Second, the diminished cuts of aspen are almost always accompanied by increased cutting in smaller diameter trees. If these diameters are unacceptable users will have to reduce their cut even further. In addition, the smaller diameters may mean increased material handling costs from harvesting through chipping or sawing, and increased difficulty and expense for industries requiring large diameter aspen as a raw material.

On the other hand, the *positive practices* projections indicate, particularly in the Wisconsin-U.P. region, that actions taken by land managers can maintain an even and increasing flow of aspen from most survey units while improving the relative condition of growing stock inventories. We are not helpless in the face of the existing and possible future condition of the aspen resource.

However, the actions necessary to effect a change mean that costs must be incurred. As in most forestry investments, the costs are incurred today whereas the benefits are received in the future and it is not always certain that the parties bearing the costs will receive the benefits. Whether these costs would, or more importantly, should be incurred was not answered by this study. We believe we have demonstrated that it is reasonably possible to maintain both an increasing aspen cut and the resource in the Lake States if we choose to do so.

# ECONOMIC OPERABILITY — FACTORS AFFECTING HARVEST AND TRANSPORT COSTS

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**ABSTRACT.** — Present forest inventories do not allow forest managers to estimate strategic transport and harvest costs for the forest resource. To improve this situation we have tested a method, originally developed in Sweden, for describing the distribution of forest inventory volumes by transport costs. We have also developed a prediction equation relating stand factors to harvest productivity for aspen pulpwood using chain saw felling and wheeled skidders. Harvest and transport cost estimates applied to the forest inventory data can yield delivered cost estimates. This kind of information can help answer important economic questions facing resource analysts.

We all agree that a forest inventory performs an essential service by giving us a broad overview of our forest resource. But it should be clear that existing procedures do not provide enough economic data to estimate harvest and transport costs.

For example, recent inventories from many areas in the Lake States suggest the need to increase the cut of aspen to balance growth and drain. These suggestions have prompted the widespread feeling that an economic surplus of aspen exists. While we may have a surplus from a silvicultural or timber management point of view, the big economic questions remain unanswered: How much timber can be cut, from which areas, and delivered to market at what cost?

Various features of this "surplus" may discourage harvest. First, the timber may exist in sparse stands, where harvesting by present logging systems is not profitable. Second, the timber may be located too far from the road system or processor to permit economic transport. And third, certain landowners will not

allow timber sales — they would rather hold the forest land for other uses.

As managers of the forest resource, acquiring the information necessary to assess the potential of the forest for economic timber harvest will help us achieve maximum benefit from all forest uses.

## WHAT IS ECONOMIC OPERABILITY?

The term "economic operability" denotes an attempt to determine the potential of the forest resource for timber harvest. It recognizes that factors, such as tree size and terrain, interact with location to determine "delivered costs." Moreover, it attempts to assemble the delivered costs for the entire inventory into a "supply" schedule. Included in this schedule would be high-volume stands situated on the mill's "doorstep" with a low delivered cost, as well as sparsely stocked stands on a mountaintop with an expected high delivered cost. In other words, all stands are operable by definition. If one is given this "supply schedule" containing all stands, one can use actual market prices to determine the volumes that might be *feasibly* harvested under the specific price conditions.

Note that our term "delivered cost" is not the same as "delivered price" used by wood buyers. When a

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<sup>1</sup> The Station's Duluth office is maintained in cooperation with the University of Minnesota - Duluth. The Laboratory at Houghton is maintained in cooperation with Michigan Technological University.

wood buyer speaks of a "delivered price" the harvest component is fixed, although he often recognizes differences in the cost of transporting the wood. Thus, in the buyer's eyes, a cord of rough aspen has the same value at roadside whether it came from an easily reached, dense stand of aspen or from a rocky crag with three trees per acre. In contrast, the concept of operability recognizes that both harvest and transport costs are dependent on a variety of factors. This is certainly a more realistic approach to assessing economic potential.

In one sense, what we are describing is nothing new; every logger estimates harvest and transport costs each time he bids on a job. The difference is, we are looking at methods that will extend conventional forest inventory systems and give useful answers on operability for an entire inventory unit.

### HOW CAN WE USE ECONOMIC OPERABILITY DATA?

If we know the delivered cost of wood from various stands in an inventory unit, we can more accurately answer questions that have plagued resource analysts for a long time. For example, owners of existing mills often ask these questions: If we expand our mill, will we have to pay more for additional wood supplies? Would any cost increases be due primarily to harvest or transport?

In areas devoid of forest industry, prospective investors ask: If we build a mill on a particular site, how much wood can we buy, in what sizes of which species, and at what cost?

Analysts ask these questions about alternate resource uses: If forest land is withdrawn from commercial use, what will the impact be on local wood industries in terms of delivered cost? Can existing mill requirements be met without delivered cost increases?

In addition, because location is such an important determinant of value, these data would allow a more objective ranking of alternative forest investments in timber management, road construction, and even land purchase.

The fact that owner intentions are ignored has variable consequences. In areas where large public

or industrial forest ownerships exist, the delivered-cost distribution of growing stock or desirable cut may be a fairly accurate picture of what is operable *and* available. But the uncertainties concerning availability will probably increase as the proportion of private ownership increases.

### OUR APPROACH

Manthy and James (1964) have described the relative importance of the three components of delivered cost for various species in the Lake States. For rough aspen trucked directly to the mill, stumpage costs averaged 12 percent, harvest costs 48 percent, and transport costs 40 percent.

Although actual "delivered prices" for a species do not reflect differences in harvest costs, we know that costs for any logging system are affected by stand and operating conditions, terrain, and climate. In a 15-month study, we found that productivity in felling and skidding tree-length aspen pulpwood varied from less than a cord to over 7 cords per man-hour. This much variation in productivity obviously affects harvest costs. By including these known variables in a suitable prediction equation, we could estimate harvest costs for a given stand of timber.

Similarly, hauling distance, truck size, and road quality all interact to determine transport costs. Manthy and James showed that transport costs ranged from \$3.00 to \$8.00 per cord when hauls ranged up to 140 miles. While actual costs have increased since 1964, similar variation probably exists today. If we can sample the geographic distribution of timber volume in relation to a road system and delivery points, we can then estimate transport costs.

Finally, samples of timber volume with their harvest and transport-cost estimates can be summarized to more accurately estimate the delivered-cost distribution of the forest resource in any inventory unit.

While many studies of harvest productivity have been carried out over the past 50 years, none is directly applicable to current methods or to the aspen cover type. Similarly, there has been a lack of research in North America to evaluate the effectiveness of forest transport systems. Mathews (1942) and Lussier (1961) suggested some optimal systems of road construction and transport for specific logging

chances, but the analysis of transport systems in forestry has been ignored.

The work of several Scandinavian forest researchers (Larson 1959, Nilsson and Segebaden 1962, and Segebaden 1964a, 1969) is directly applicable to questions of harvest and transport cost. They have developed several methods to (1) measure the economic impact of a road system on forest use, (2) integrate general transport-cost data with harvest-cost distributions of growing stock, and (3) apply these results to real problems.

From this work, we developed a three-phase study of economic operability. First, we conducted a study of aspen pulpwood harvesting that related productivity to the stand factors gathered by forest survey. Second, we modified and tested the Swedish methods for describing forest access and its impact on transport costs. Third, we are developing computer programs to combine harvest and transport-cost information with regular forest inventory data. Although this entire effort is aimed primarily at aspen, it also has application to other species and cover types.

## PRODUCTIVITY OF PULPWOOD HARVESTING

The aspen type was chosen because of its large and growing economic importance in the Lake States. Although several logging systems are used for harvesting aspen pulpwood in north-central Minnesota, we studied the most widely used system — tree-length logging with chain saw felling and wheeled skidders.

Because it was impractical to do our own logging and control all variables that influence productivity, we conducted an observational study of aspen pulpwood logging. We used a gross-data approach, which measures gross inputs of man and machine time and the output of wood. Because stand and terrain factors may change as harvest proceeds through a stand, work areas averaging 15 acres were measured each week. For the next 7 days, the logger himself recorded daily man-hours, machine-hours, approximate skidding distances, weather conditions, and wood output. This process started in July 1969 and was repeated weekly for each of five cooperators until September 1970; 238 workdays on 42 work areas were examined.

The principal stand factors of the work areas ex-

amined were: Harvestable volume per acre averaged 17.6 cords but ranged from 2.5 to 38.0 cords. The number of harvestable trees per acre averaged 151 and ranged from 35 to 383. The number of harvestable trees per cord averaged 8.6 and ranged from 2.6 to 16.1. Total daily production averaged 24.8 cords and ranged from less than a cord to 96 cords. Total daily production of trees averaged 203 and ranged from 3 to 898.

Productivity for felling and skidding functions averaged 1.26 and ranged from 0.03 to 7.49 cords per man-hour. In trees per man-hour, productivity averaged 10.3 and ranged from less than 1.0 to 38.7.

We found that the *number of trees harvested per man-hour* (felling through skidding) is a function of (1) the ratio of harvestable trees per acre to total trees per acre, (2) harvestable volume per acre, and (3) spacing of the nonharvestable stand. Trees per man-hour can be converted to cords per man-hour given mean volumes per tree for the stand. This step avoids the errors of estimating individual tree volumes as the logging takes place. It is also more realistic because logging is primarily piece-oriented and not volume-oriented; that is, it takes almost the same time to fell and skid a small tree as it does a large tree.

Our best equation took the following form: trees per man-hour (felling through skidding) =  $8.343 + 19.455 \times \text{ratio (harvested trees/acre} \div \text{total trees/acre)} - 0.347 \times \text{harvested volume /acre (cords)} - 0.138 \times \text{equilateral spacing}^2 \text{ of nonharvested trees (feet)}$ .

How reliable and applicable is this equation? It did explain one-half of the variation in the data,  $R^2 = 0.49$ . Although this equals the amount of variation explained by other more detailed production studies, it still means that individual estimates of productivity using our model will have a large possibility for error. While it may not be accurate enough for a logger to use in his day-to-day harvest-cost estimates, we feel that it is accurate enough to estimate harvest costs over a forest inventory unit.

On the other hand, it deals only with one harvest system — chain saw felling and wheeled skidders.

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$$^2 \text{ Equilateral spacing in feet} = \sqrt{43,560 \div 0.866 \times \text{tree/acre.}}$$

Other systems are in use and more mechanized systems are growing in popularity. In this sense, its application is limited. It does serve as an example of what can be done and it could be used to summarize operability for aspen pulpwood in selected study areas.

Although the productivity estimates have not been converted to harvest costs per unit volume, this can be done for specific labor and machine rates and overhead charges.

## FOREST ACCESS AND TRANSPORT COSTS

The method used in our study of forest access was developed primarily by Segebaden (1964b). It relates transport distances and costs to (1) road network length per unit area, (2) road network distribution (geometry), (3) terrain, and (4) a specific delivery point. In his system the theoretical parameters describing an ideal road network are modified by two correction factors to permit the consideration of real road networks. This procedure answers two questions: (1) How far is the nearest road from any given stand of timber? (2) How far must a given volume of timber be transported to market?

In practice, inventory plots were located on aerial photos or maps. Straight-line distances were measured from each plot to the nearest road and then to the delivery point. While only one destination may be considered during each measurement of a forest inventory unit, additional points can be considered in successive measurements.

Because a distribution of timber volumes by transport distance and cost would be useful by itself, we developed a computer program to deal solely with timber transport. This FORTRAN IV program entitled ACCESS summarizes forest inventory data by transport distance and cost for each cover type and species.

Two kinds of transport-cost histograms can be constructed from these summaries. One kind (fig. 1) shows the volumes transportable at each of several cost levels. For example, the first point shows that 2,200 cords can be transported to market for \$4.70 per cord. The second point shows that the next 215,000 cords can be transported for \$5.00 per cord.

Of more value, however, is a cumulative distribution of volume by transport cost (fig. 2). This histogram shows cumulative volumes transportable to the delivery point at a cost equal to or less than any specified cost maximum. For example, the first point shows, as it does in figure 1, that 2,200 cords can be transported to market for \$4.70 per cord or less. But the second point shows that 217,200 cords (215,000 plus 2,200) can be transported to market for \$5.00 per cord or less. Note the change of scale on the vertical axis between figures 1 and 2.

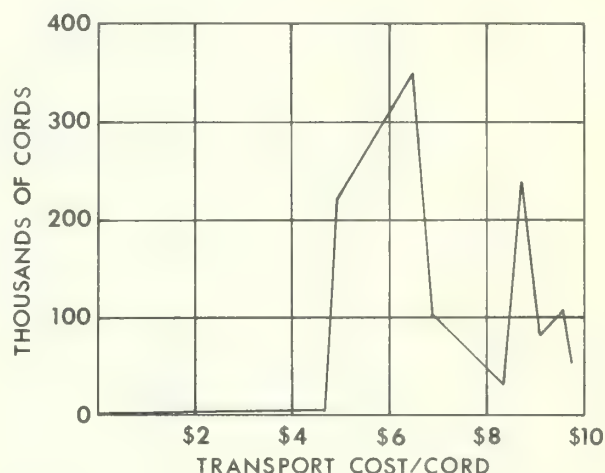


Figure 1. — Distribution of aspen growing stock on Koochiching County lands by transport costs to International Falls.

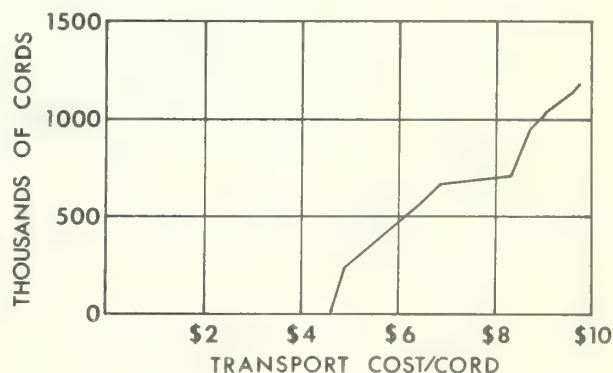


Figure 2. — Cumulative distribution of aspen growing stock on Koochiching County lands by transport costs to International Falls.

These data are of immediate value to the wood procurement manager. Putting this information in perspective with his wood requirements, it could indicate an upper limit to the wood he can expect to receive with the specific transport costs he can afford. Looking further, he can consider changes in the road system and construct new transport-cost histograms. He can then compare the effect of existing and planned road nets on the transport-cost distribution; will the investment pay off in reduced transport costs?

While the development and testing of a new process is always a challenge, the real task is applying it to actual problems. This method was applied to the forest inventory data of Koochiching County, Minnesota, to demonstrate the ease and low cost of gathering transport-cost information. From this work we developed transport-cost distributions for all cover types and species. The inventory data were 10 years old and the results did not warrant publication, but a summary of the methods employed will be published soon. We are now applying the method to current inventory data in Michigan's Upper Peninsula. This will provide a realistic test of our procedures.

### PUTTING IT ALL TOGETHER

Economic operability is an important concept. By relating harvest and transport costs to forest survey data, we hope to give land managers a better idea of the forest's economic potential for timber production. Our most significant development has been achieved with forest access and its effects on transport costs. These methods, originating in Sweden, are simple, inexpensive, and can shed light on many important questions.

Results of our efforts to relate stand factors to harvest productivity and cost are less clear. While we were able to derive a good prediction equation for the broad strategic purposes intended, the work points out one major problem: logging systems are dynamic. Yet our study, which examined only one cover type and harvest system, took 2 years to complete. This

suggests that estimating harvest costs for all commercially important cover types rapidly enough to avoid obsolescence would be a large task indeed.

A more rapid and flexible way must be found to examine how man and machine systems interact with stand factors. Computer simulation seems to offer substantial advantages. Instead of dealing with whole systems, the effect of environmental factors on individual components could be studied in closely controlled experiments. Given system characteristics, computers could rapidly evaluate many alternative combinations. Only highly promising systems would be actually field tested.

We hope the need for economic inventory data has been highlighted. Certainly something must replace the existing groping for answers about economic feasibility. To achieve this goal, however, more than a token research effort must be made to find the most effective means for gathering the needed information.

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# THE ECONOMIC IMPACT OF HYPOXYLON CANKER ON THE LAKE STATES RESOURCE<sup>1</sup>

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**ABSTRACT.** — A 1971 field survey comprised of 196 sample locations randomly distributed over the aspen type in Michigan, Wisconsin, and Minnesota, showed the following effects of hypoxylon canker: The average proportion of live aspen trees currently infected in the Lake States aspen type is 12.1 percent. Observed infection rates ranged from zero to 40 percent. The average proportion of the aspen-type area that will be denuded by the observed rate of infection is 5.6 percent. This reduction in stocked area means an eventual reduction in the aspen harvest each year of 21 cubic feet per acre or 300 million cubic feet for the type as a whole. The value of this loss will be in excess of 4 million dollars per year at harvest, and is more than 2 million dollars per year in present value terms.

## HOW FARES THE ASPEN?

Aspen is an important Lake States timber type. It extends over 14 of the 52 million acres of commercial forest land in Michigan, Minnesota, and Wisconsin. Recently aspen has become very much more important commercially, as well. It made up one-half of the 4-million-cord Lake States pulpwood harvest in 1970, and its use undoubtedly will grow still larger in the future.

How fares the aspen? In most respects aspen is an easily managed pulpwood type. Reproduction is obtained by clearcutting and the root suckers that result typically are abundant and vigorous. This relatively intolerant tree expresses dominance well, and

overstocking to the point of stagnation is not encountered. Thus, growth without intermediate management is reasonably good, with production of about 40 cords per acre at 50 years typical for fully stocked stands on better sites.

Diseases, however, are a serious problem, often causing large losses. Hypoxylon canker is the most important killing disease of aspen. This virulent pathogen causes mortality in 3 to 7 years after lower bole infection. It is widely distributed and evidence of the disease can be found in almost all aspen stands. An effective means of chemical or silvicultural control is yet to be identified. How serious are the losses resulting from hypoxylon canker? How urgent is a search for control? These are the questions to which this study is addressed.

## LOOKING FOR HYPOXYLON INFECTION

In the summer of 1971 field crews visited 196 sample locations distributed throughout the aspen type of Michigan, Wisconsin and Minnesota. To insure representativeness, the total sample was allocated among Forest Survey units by the proportion of total aspen acreage falling in each unit. The sample locations within each unit were drawn at random from the Forest Survey aspen plots available

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there. Field crews revisited these selected plots and used the survey plot center as the starting point for this infection survey.

Each sample consisted of a line of 25 circular plots 7 feet in radius and placed at 25-foot intervals. The first 20 live trees on each plot were examined and classified into four categories:

1. Aspens not fatally injured or infected.
2. Aspens with hypoxylon (*Hypoxylon pruinaum* Cke.) infections.
3. Aspens fatally infected or injured by another vector only.
4. Non-aspen tree species.

Each live aspen also was separately classified according to whether or not it had conks or target-shaped cankers. In addition, site quality was estimated by determining the height and age of three main-stand aspen dominants, and main-stand size class and species composition were noted.

## THE INFECTION AND DENUDATION WE FOUND

The average percentage of live aspen trees currently infected in the Lake States aspen type is 12.1  $\pm$  1.0 percent with a probability of 0.95. The range in observed infection rates was zero to 40 percent.

Table 1 shows infection rate findings in more detail. It is clear that bigtooth aspen is far less susceptible to infection than quaking aspen. Some site and stand condition factors may also be correlated with infection rates, but further sampling and analysis will be needed to establish these.

Other disease problems were much less prevalent than hypoxylon canker. Conks were found on 1.9 percent of the aspen examined and target-shaped cankers were found on 2.5 percent.

Each of the 25 plots examined at a sample location represented the minimum area needed to support a merchantable tree at harvest. Plots where all live aspen had hypoxylon infections were plots that would be denuded, and that stand area might not support an aspen crop-tree at harvest. Plots where one or more uninfected trees exist were plots that would not be denuded by current infection, and thus no volume loss would result. We found that  $5.6 \pm 1.6$  percent of the aspen type would be denuded by current infection with a probability of 0.95.

The amount of area lost to current infection is a function both of the rate of infection and the density of stocking. The same infection rate will cause less denudation where stocking is high than it will where

Table 1. — *Proportion of live aspen infected with hypoxylon canker, Lake States, 1971*

Item	Infection rate	Basis
	Percent	No. observations
By species:		
Predominantly bigtooth aspen	2.7	14
Mixed bigtooth and quaking aspen	7.8	25
Predominantly quaking aspen	13.7	157
By 30-year aspen site index:		
40	9.7	19
45	16.8	12
50	13.3	63
55	11.9	41
60	12.4	41
65	9.6	8
70	8.5	12
By stand size class:		
Sapling stands (ave. d.b.h. 0-3.9 in.)	9.1	27
Pole stands (ave. d.b.h. 4.0-7.9 in.)	13.5	109
Timber stands (ave. d.b.h. 8.0 in.+)	11.0	60
By State:		
Michigan	9.5	61
Wisconsin	13.2	54
Minnesota	13.5	81
Lake States Average	12.1	196

aspen stocking is sparse. The following linear, multiple regression relationship accounted for 78 percent of the total variation in percent of area denuded:

$$\begin{aligned} \text{Percent area denuded} = & 0.5425 (\text{current infection rate}) \\ & - 0.0021 (\text{No. aspen per acre}) \end{aligned}$$

Both determining variables are significant at the 99 percent confidence interval. Figure 1 shows expected denudation percents by current infection rate and for a range of representative aspen stocking levels.

The current average denudation rates by State are shown in this listing:

State	Denudation Rate Percent
Michigan	3.7
Wisconsin	5.9
Minnesota	6.8

The listing makes it evident that Michigan is currently experiencing the smallest proportion of area denuded, and Minnesota the greatest.

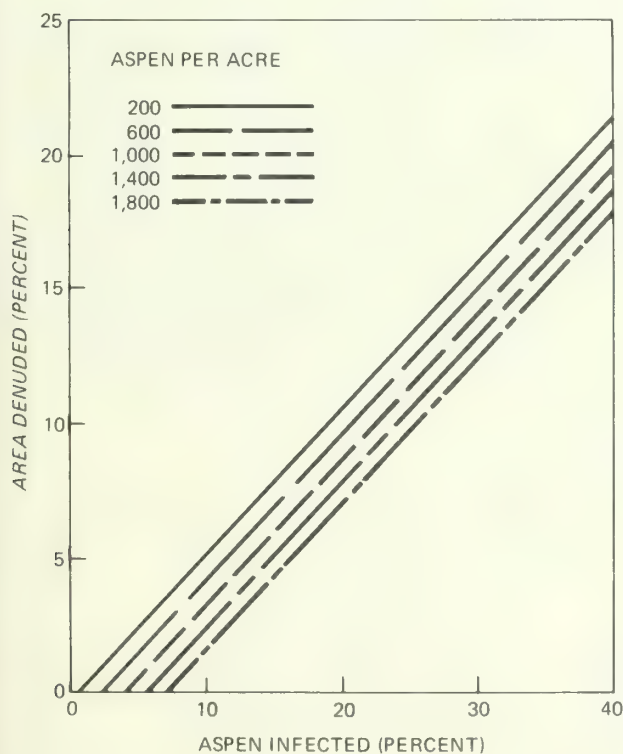


Figure 1.—Relationship between percent area denuded, infection rate, and stocking density.

## HOW DENUDATION WAS TRANSLATED TO IMPACT

The model used to estimate volume and value impact is shown in figure 2. The loss which eventually will be occasioned by hypoxylon infection and denudation dating from a given year depends on these factors:

### Volume Loss

Little or no reduction in harvest volume occurs until an area has been denuded that is approximately equal in size to that needed to support a tree of harvestable size. An aspen 8 inches in d.b.h. requires about 150 square feet of stand area — an area equivalent to a circular plot with a 7-foot radius. Denudation estimates in this study are based on the presumption that most aspen stands that are harvested at all will be harvested soon after they contain a harvestable volume of pulpwood, and that the average size of tree harvested will be approximately 8 inches in d.b.h. For the small proportion of the aspen resource that will be harvested at a larger size, this study overestimates denudation.

The percent of crop-tree areas denuded during a period, multiplied by per acre full-stocking volume at harvest, provides an estimate of the maximum volume loss per acre. Denudation in younger stands will be made up in part by restocking and especially by faster growth of surrounding aspen. This study assumes that recovery will occur at 15 percent per decade on a volume basis. Since trees with evident infection usually die within 3 to 5 years, it was assumed that the annual infection and denudation rates are one-fourth of those observed.

The full stocking volume at harvest is a function of site index and harvest age. The volumes and harvest ages assumed in this study are shown in table 2. The harvest ages are the stand ages at which the average d.b.h. of trees above 5 inches reaches 8 inches, or at which growth falls below  $\frac{1}{2}$  cord per acre per year, whichever age is greater. Harvest volumes are stated in cubic feet and to a 4-inch top and have been adjusted to lie between the reported yields for quaking and bigtooth aspens.

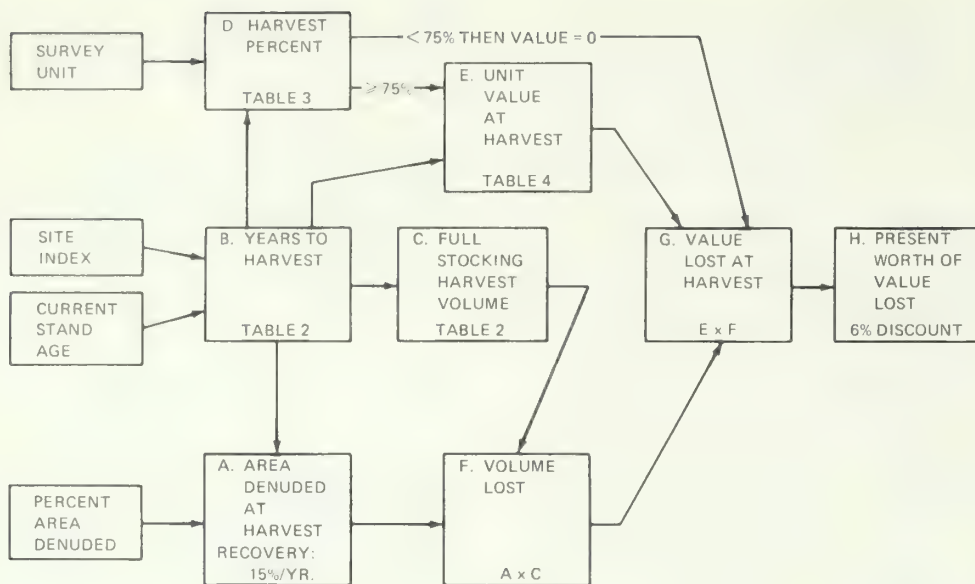


Figure 2. — Model for estimating volume and value impacts.

### Unit Value

The value of yield losses depends on whether or not that volume would have been harvested and utilized, and if so, the income created thereby for the owner, the logger, and processor. The likelihood of harvest varies considerably from one area to another within the Lake States. Actual aspen harvest currently is less than annual growth for most Lake States Forest Survey units. A projection of these current data was used as a basis for estimating the proportion of annual growth likely to be harvested in future decades, and is shown in table 3. No economic loss is assumed in this study for survey units

where harvest is expected to be less than 75 percent of the annual aspen growth during the harvest decade. Volume reductions in these instances are very likely simply to shift harvest to other acres, rather than to cause a reduction in harvest. The conversion return, or economic value, of aspen depends on how it is utilized and upon processing costs and product prices. Projections of conversion return by average stand diameter are shown in table 4.

### Present Value of Losses

The present value of the economic loss was estimated by multiplying the volume loss by its expected

Table 2. — Anticipated aspen harvest age and harvest volume<sup>1</sup>

30-year site index (feet)	Expected harvest age	Expected full-stocking harvest volume (cu. ft. per acre)				
		Current stand age less than expected harvest age	Current stand age greater than expected harvest age			
			45	50	55	60
Years						
40	40	850	900	900	850	800
45	40	1,100	1,150	1,150	1,100	1,050
50	40	1,350	1,400	1,400	1,350	1,300
55	40	1,700	1,800	1,800	1,750	1,700
60	45	2,400	--	2,650	2,650	2,600
65	45	3,200	--	3,600	3,700	3,700
70	50	3,900	--	--	4,500	4,600

<sup>1</sup>/ Adapted from Graham, Samuel A., et al. 1963. *Aspens*. Ann Arbor: Univ. Mich. Press. Tables 2-13, p. 70-79.

Table 3. — *Anticipated aspen harvest as a proportion of anticipated growth<sup>1</sup>*

State and Survey Unit	Harvest percent when years-to-harvest is:						
	0	5	10	15	20	25	30
Michigan:							
Eastern Upper Peninsula	66	69	73	76	80	84	88
Western Upper Peninsula	77	81	85	89	94	98	100
Northern Lower Peninsula	91	96	100	100	100	100	100
Southern Lower Peninsula	100	100	100	100	100	100	100
Minnesota:							
Lake Superior	26	27	29	30	32	33	35
Central Pine	33	35	36	38	40	42	44
Rainey River	51	54	56	59	62	65	68
Southeastern	35	37	39	41	43	45	47
Western	55	58	61	64	67	70	74
Wisconsin:							
Northeastern	95	100	100	100	100	100	100
Northwestern	76	80	84	88	92	97	100
Central	100	100	100	100	100	100	100
Southeastern	77	81	85	89	94	98	100
Southwestern	7	7	8	8	9	9	10

<sup>1</sup>/ Assumes that greater utilization pressure will increase current utilization by 5 percent every 5 years.

Table 4. — *Anticipated conversion return for aspen<sup>1</sup>*  
(In dollars per thousand cubic feet)

30-year site index (feet)	Value when years-to-harvest is:						
	0	5	10	15	20	25	30
40	25	28	31	34	37	40	43
45	25	28	31	34	37	40	43
50	25	28	31	34	37	40	43
55	25	28	31	34	37	40	43
60	28	31	34	37	41	44	47
65	28	31	34	37	41	44	47
70	31	34	37	40	45	48	51

<sup>1</sup>/ Current average stumpage price is approximately \$2 per 100-inch cord, which contains about 80 cubic feet. This converts to \$25 per M. cu. ft. National projections of timber supply and demand indicate price increases of 73 percent by the year 2000. A straight line projection is employed. Increases in average stand d.b.h. above the 8-inch average typical of harvest from low site stands create added value because of conversion to different end products (lumber and veneer), and the lower cost of logging and conversion. An increase of 10 percent in value per inch of average d.b.h. is assumed here.

unit value, and then discounting this value from the expected harvest date to the study's base period (1971) at a 6 percent discount rate.

## IMPACT FINDINGS

Table 5 shows average infection and denudation by State, and the volume and value impacts projected both on a per acre basis and for the type as a whole. The physical impact of hypoxylon is most serious in Minnesota, where infection, denudation

and resulting volume losses are greatest both relatively and absolutely. However, the economic impact is concentrated in Michigan and particularly in Wisconsin, where little excess of annual growth over cut is anticipated in the future.

The 300 million cubic feet of volume, which this study estimates will be lost each year as the result of current infection, is approximately equivalent to the annual net growth for the type (332 million cubic feet) and the "desirable" harvest level (284 million cubic feet). In other words, annual growth and utilization could be doubled if hypoxylon were eliminated. These volume impacts are based on the infection and denudation currently happening. Current hypoxylon infection and denudation may be greater or less than is typical — we have no way of knowing this. But impacts on the order of those projected in this study are probably the rule rather than the exception in most years.

It appears likely that for some time the volume of merchantable aspen added to the inventory each year will far exceed the volume harvested in Minnesota, in the eastern end of the Upper Peninsula of Michigan, and in southwestern Wisconsin. In these areas volume losses due to hypoxylon will not reduce harvests. Thus, there is little urgency for control in these areas. However, for the remaining area, where there is little or no excess of anticipated growth over anticipated harvest the situation is different. Harvest

losses are large — 4.4 million dollars per year at time of harvest and 2.3 million dollars per year in present-value terms (table 5). So effective control could produce very substantial economic benefits.

A final word is needed regarding nontimber impacts. Aspen is a favored food of deer and beaver. Hypoxylon infection typically causes small openings that reproduce to deer browse species. Deer herds

probably are favored to some extent by the disease because hypoxylon increases the amount of reachable browse. This change in aspen cover probably does not influence the beaver substantially. With regard to scenic impacts hypoxylon probably causes some reduction in attractiveness, but again, this impact is not substantial in my judgment, since extensive killings and denudations are the exception rather than the rule. Most infection is scattered in small patches and does not markedly alter the vista.

Table 5. — *Summary of current Hypoxylon infection, denudation, and impact, by State*

HYPXYLON INFECTION, DENUDATION, AND IMPACT					
State	Infection rate <sup>1/</sup>	Denudation rate <sup>1/</sup>	Harvest volume lost	Harvest value cost	Present value of losses
	Percent of trees	Percent of area	Cu. ft./acre	Cents/acre	Cents/acre
Michigan	2.4	0.9	12.5	34.2	16.1
Wisconsin	3.3	1.5	22.4	64.6	33.8
Minnesota	3.8	1.7	28.2	.0	.0
Total	3.0	1.4	21.0	30.9	15.6
TOTAL ANNUAL IMPACT FOR THE TYP.					
			Million cu. ft.	Million dollars	Million dollars
Michigan	--	--	53.2	1.456	.686
Wisconsin	--	--	93.6	2.965	1.551
Minnesota	--	--	153.7	.000	.000
Total	--	--	300.6	4.421	2.337

1/ Current infection and denudation divided by 4, the number of years of activity that current infection is assumed to represent on the average.

# SELECTED ECONOMIC ASPECTS OF MANAGEMENT

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**ABSTRACT.** — This paper briefly examines, from an economic point of view: (1) some characteristics of the aspen resource in general, (2) some extensive and intensive timber management applications in aspen, (3) multiple use and community impact evaluation frameworks, and (4) some research needs. Financial incentives over the near future are not favorable for more intensive aspen management, but changes in costs, prices, and values of nontimber products could change this somewhat pessimistic outlook.

All of the topics included in this Aspen Symposium have economic aspects and implications for management. The purpose of this remark is not the establishment of a pivotal role for economics and economists in aspen resource analysis. The purpose is simply to emphasize the necessarily narrow, selective, and sometimes conjectural nature of our presentation which results primarily from basing our paper on relatively limited existing data.

Our presentation is simple and straightforward. We begin with an economic overview of our aspen resource. We then identify a set of general timber production options or alternatives that seem appropriate for aspen as well as other species-type evaluations. We also consider economic evaluation frameworks that represent alternatives to the traditional single product economics analyses applied to timber growing. Finally, we have a word or two to say about some information needs that we think bear strongly on further application of economics to aspen management problems.

## AN ECONOMIC VIEW OF THE ASPEN RESOURCE AND UTILIZATION OPPORTUNITIES

Aspen emerged explosively from the status of weed-tree or nonresource in the post-World War II period. Rapid exploitation over most of its range has a history of less than 25 years. Aspen is the primary species for pulpwood production and has become increasingly

important in the three Lake States over the past 11 years (fig. 1). Trends have been similar in all three States; however, the proportion of production retained in-State (versus export to Wisconsin) has increased for both Michigan and Minnesota. It seems relatively certain that Lake States aspen harvests cannot continue to accelerate indefinitely, and the historical trend lines of figure 1 must flatten out as "old growth stocks" inherited from the past are liquidated, other things being equal.

Graham *et al.* (1963) projected a scarcity of harvestable aspen stands commencing in the 1975 to 1985 period. Within the relatively brief interval since this projection was published, annual aspen consumption has increased 12 percent and merchantability criteria have drifted downward, as has the accepted rotation age. In addition, early pathological deterioration and continuing high levels of harvests have continued to shift growing stock distribution to younger age classes. The net effect is that the impending hiatus in aspen availability has probably been moved ahead 5 years, but not eliminated.

There are two ways of looking at the aspen resource — as a stock or woodpile and as a flow or potential continuous yield. If the aspen resource is considered a "flow," decisions must be made as to how the following basic inputs of aspen production will be allocated: (1) land, (2) capital resources other than growing stock, (3) growing stock (allocated either to current harvest or future harvest), and (4) har-

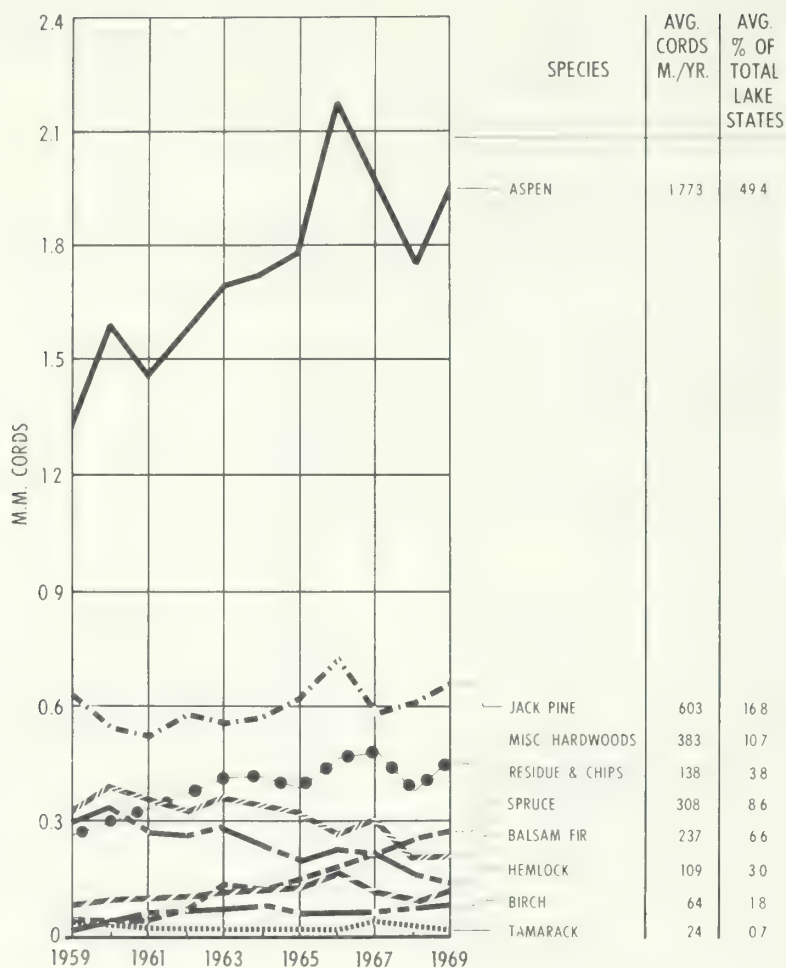


Figure 1. — *Lake States pulpwood productions by species, 1959-1969.*

*Source: Horn (1960) and Blyth (1967).*

vested material (allocated to various end uses). Allocation of harvested material is discussed below.

Noreen and Hughes (1968) have presented a conversion-return analysis of allocation of aspen logs by diameter class to pulpwood use, lumber uses, and plywood use. The results of the study can be simplified to a comparison between pulpwood and structural products (plywood and lumber). When no return for residues was considered, 8-inch logs yielded their highest conversion return in pulpwood, and structural uses provided significantly higher returns only beyond the 10-inch diameter class. When allowance was made for residue values, however, structural uses yielded significantly higher returns in all diameter classes above 8 inches.

The above analysis is based on log diameters and not average stand diameter breast height (d.b.h.). The following factors will force these threshold diameters upwards: sorting costs, structural product producers' need for acceptable rates of return to fixed capital overtime, quality premiums that the log market will exact for "woods run" of higher diameter, and dispersion of actual d.b.h. about average stand d.b.h. and reduction of log diameters in the upper stem. If we are searching for a criterion of average stand d.b.h. to distinguish pulpwood sites from structural timber sites, including considerations of rotation or efficiency over time for production, we might suggest a "rule of thumb" criterion for a structural aspen timber site as being a site capable of producing an average d.b.h. of 10 inches in 50 to 60 years. The

most recently available aspen yield model (Ek and Brodie)<sup>1</sup> indicates that site class 70 will have an average d.b.h. of 8.7 inches at age 55, while site class 80 will have an average d.b.h. of 10.1 inches under similar stocking assumptions.

The above speculative analysis leads to the conclusion that only a small portion of the Lake States aspen sites (mostly in the northern counties) can be managed suitably for structural products. We note, however, that a site index 70 stand will have an average d.b.h. of 12.5 inches at age 80; and even site index 60 will have an 80-year average d.b.h. of 10.6 inches. Thus, a higher proportion of existing aspen growing stock might best be allocated to structural products, even though the second rotation harvest should probably be allocated to pulpwood.

Our discussion has dealt primarily with the aspen resource as a source of timber. The strong positive correlation between young aspen stands and grouse and deer productivity provides a direct nonmarket benefit of aspen management that may justify aspen regeneration activity on borderline commercial timber sites. Aspen timber management has a real potential to be complementary to wildlife production.

## SOME TIMBER PRODUCTION OPTIONS

We are concerned here with three general classes of management options for aspen timber production: (1) extensive management or a simple "cut-and-let-grow" option with a major focus on amount of land area to allocate to aspen harvest, (2) intensive management with a focus on time and stocking control alternatives, and (3) type control and conversion options which consider not only the amount of land to allocate to aspen harvests but also the complete replacement of aspen by alternative species and by various means. These are all broad classes and we discuss only a few aspects of each below.

### Extensive Management

The simple "cut-and-let-grow" option that seems to correspond to past practice, has not been chal-

lenged significantly by current economic conditions and is supported at least in part by recent research. Sorensen (1968), for example, has shown that the size of crop trees in 15-year old aspen regeneration following commercial clearcutting varies little over a wide range of initial sucker densities on good sites. This at least tends to weaken the argument for the application of intensive cultural practices such as thinning in young aspen stands to improve the size of residual trees in a given period of time. Another study,<sup>2</sup> concerned with the economics of young growth aspen thinning, showed that even on the best sites, given current costs and prices, it was more profitable *not* to thin than to thin. Others, however, contend that intensive management practices such as thinning will pay off and we refer to some of this argument below.

Associated with extensive management are questions of protection and stand or forest manipulation for the production of other-than-timber benefits. We would tend to argue, from a strictly financial point of view, and based upon no particular data, that the expenditure of extra funds on such practices ("extra" in the sense of more than "normal") would not yield a commensurate increase in benefits saved or produced, given current costs and prices. We would tend to argue instead that the burden of "management" should fall upon the timber harvest operation in terms of such things as adjustments in size and distribution of cutting units, slash disposal, and time sequence of harvest in stands of different ages and condition. All of these, of course, may have an impact on logging costs and, hence, on stumpage prices. Ultimately, there would be an impact on logging technology. We believe the current interest in mechanized harvesting equipment and systems is a forecast of this "ultimate" impact.

### Intensive Management

Intensive management for timber production can be viewed for convenience as conscious control of the time and stocking variables of the production process. Other "intensive management" practices such as fertilization, irrigation, etc., will affect financial outcomes, to be sure. However, we believe that the

<sup>1</sup> Ek, A. R., and J. D. Brodie. *Yield potential of short rotation aspen. Sixth TAPPI For. Biol. Symp. Proc.*, Appleton, Wis., May 1-3, 1972. (In preparation.)

<sup>2</sup> Noreen, Paul A. 1968. *Economic evaluation of precommercial thinning in good-site aspen.* (Unpublished M.S. Report, Coll. For., Univ. Minn. 19 p.)

primary timber management decisions are those relating to time and stocking control, *given* the entire set of other factors for a site which are usually fixed in some proportion to each other and which in turn will account for variation from site to site or stand to stand when the same time and stocking controls are applied to all sites.

Several studies in addition to those already cited have been concerned with the time and stocking aspects of aspen timber production and illustrate a continuing interest in intensive management of aspen if not an overwhelming level of research. Twenty-five years ago Zehngraff (1947) observed that precommercially thinned aspen yielded larger and sounder logs than did unthinned stands harvested at the same age. Steneker (1964), as a later example, observed that perhaps as much as 10 years can be eliminated from the rotation for aspen saw logs and veneer logs if precommercial thinning (that is, stocking control) is followed. Therefore, the results of research so far, when those like Sorensen's on the one hand and Zehngraff's and Steneker's on the other are compared, do not seem to provide clear management direction. We offer a few additional observations below, primarily from an economic vantage point.

## Short Rotation Management

Time control can be of several kinds: length of time permitted for regeneration following harvest, age of stand at first thinning, time between intermediate harvests or thinnings, length of cutting cycle, and time of harvest or rotation period. We suspect that most interest in time control in intensive management of aspen is focused upon the control of rotation period because aspen: (1) is a relatively fast growing species, (2) aspen provides an increasingly large share of total roundwood consumption for such products as pulpwood especially in the lower diameter classes, and (3) growing time to maturity has a cost (interest) in financial evaluations and reduction of this cost may be the most easily accessible means for improving the economic acceptability of aspen as a fiber crop.

Inquiry into very short rotation management is in its early and extremely speculative stages. Already, however, it is divided into two different approaches with different associated speculative technologies.

The first approach might be described as agronomic short-rotation management using improved genetic stock and intensive crop-tending inputs similar to agriculture. Rotations of considerably less than a decade are envisioned under this system.

The second approach might be described as "extensive short-rotation management" and involves harvest and regeneration of natural aspen stands with full utilization of small stems and branch wood. Since the analytic technique and methods of this approach are reported elsewhere<sup>3</sup> only major conclusions will be discussed here.

The first conclusion of note is that potentially feasible short rotations under this approach are not nearly as short as under the agronomic approach. They fall in the range of from 12 to 25 or more years because total volume is accumulating at an accelerating rate for more than a decade.

The second major conclusion is that sustained yield is not significantly reduced by these short rotations because yield functions are approximately linear over large segments of the relevant range. When this condition prevails, losses in yield from rotation shortening are counterbalanced by increases in the land area from which the harvest comes. This could have a significant effect on harvesting costs but not on available harvest volume.

A third conclusion, that should have been obvious *a priori* but required several computer simulation runs to verify, was that these short rotations are not particularly sensitive to large shifts in discount rate. A shift in discount rate from 5 to 8 percent under a particular set of assumptions resulted in rotation being lowered only from 17 to 16 years. Examination of the soil rent formula

$$\frac{Y_t}{(1.0p)^{t-1}}$$

indicates why this should be. The exponential term "t" does not possess the sting that it would in the conventional rotation age range of 35 to 70 years. This allows substantial variation in "p" with only a small effect on rotation.

<sup>3</sup> Ek, A. R., and J. D. Brodie. *Op. cit.*

Adoption of this management technique requires development of manufacturing processes that can handle the small material that develops. It also requires the development of harvesting technology that will handle the harvested material at from 75 to 50 percent of current pulpwood materials handling cost. The advantages of this system, other than those above, would include a reduced period over which harvestable stands would be subject to hazards and pathogens and thus a utilization of material currently lost. There would also be a very substantial liquidation gain if landowners cut back rapidly to the growing stock levels implied by shorter rotations. This would offset any short-term shortage of harvestable aspen and perhaps bring about more rapid utilization of deteriorating stands.

### Stocking Control

"Stocking control" is a general term that includes such timber management concerns as initial stocking rates in plantation or natural stands, and residual stocking levels following thinnings or harvest cuts. It can be measured in various ways including stems per acre, basal area, and volume. Several of the studies previously cited, plus those of Pike (1953) and Day (1958), deal with stocking control. We wish to refer here, however, to only one study which has some economic inferences.<sup>4</sup>

Noreen compared the internal rates of return from two different thinning systems (a single precommercial thinning and a single precommercial thinning plus one commercial thinning) with no thinning in young growth aspen (thinning ages ranged from 4 to 30 years) on good aspen sites. After-thinning stocking levels were those judged by experienced forest managers to give the best results. For instance, it was assumed that 70 square feet of basal area would remain after the commercial thinnings because this level was recommended by the USDA Forest Service for aspen management. The result of this analysis was that regardless of rotation or thinning alternative considered, the "no-thinning" alternative had the highest rate of return.

The inference seems to be that at present prices and costs stocking control in aspen by thinning is not worthwhile financially. Although this analysis

considered only one level of stocking and few thinning alternatives, it was based upon the best available judgment of the best apparent opportunities for aspen thinning payoff.

### Time and Stocking Control

Although time control and stocking control decisions are individually important, the forest manager is more interested in the best *combination* of time and stocking levels in the timber growing process. Noreen<sup>5</sup> is used again to provide some economic inference.

Evaluation of rotation alternatives ranging from 20 to 55 years, for good site aspen, and no thinning, showed that rotations of 30 to 35 years yielded the highest rates of return (from 1.69 to 6.81 percent) given various cost and price assumptions. Interestingly, the short 20-year rotation required the highest price-lowest cost assumption in order to realize as much as a 1.88 percent rate of return. Thus, the best combination of time and stocking control for good site aspen in this study, using maximum rate of return as the criterion, was "no thinning" and a rotation of 30 years. This result also reflects the "high price" assumption of the study. Lower price assumptions yielded a somewhat longer rotation of 35 years (40 in the case of the high cost-low price assumption); but the best stocking control was still "no thinning."

### Type Control and Conversion

We refer here to the typically most drastic attempt by man to manage the forest environment for his own purpose. Type control entails the complete replacement of any forest cover type with another type, either suddenly by some means such as shearing and planting, or perhaps slowly by single tree selection harvests in a shade intolerant forest cover type. We know of many examples of aspen stand replacement throughout the Lake States. Typically, sheared areas are planted to white spruce or red pine. Typically, too, the costs of conversion by this method are high. The rationale seems to be largely that the species presently of higher value, such as white spruce and red pine, have better prospects for long-term value yield.

We have not evaluated type conversion from an

<sup>4</sup> Noreen, Paul A. *Op. cit.*

<sup>5</sup> *Ibid.*

economic standpoint nor do we know the acreage converted throughout the aspen range. However, we think it deserves the immediate attention of solid economic analysis in view of the high initial investment, the long time period required to realize a pay-off, the increasing importance of aspen as a source of wood, and the increasing importance of the aspen cover type for the production of other forest products such as wildlife.

## **ALTERNATIVE ECONOMIC EVALUATION FRAMEWORKS**

We have focused our discussion to this point on more or less traditional timber production economics. While production economics is interwoven either directly or indirectly with all aspects of forest management, consumption and welfare foci are shifting priorities for forest management and for economics research in forestry in response to a new wave of public concern for environmental quality and its implications for economic development. We would like to mention very briefly two more or less definitive but certainly not new frameworks for economic evaluation of aspen management: (1) multiple use, and (2) community impact.

### **Multiple Use**

We believe that multiple use management, in spite of our individual and collective hang-ups regarding precision of operational definition, is appropriate for dealing at least in part with forest environmental quality. Multiple use management explicitly recognizes the "jointness" of forestry production in the sense that whatever we do to the forest environment is likely to affect the level and quality of more than one of the several "products" of the forest. These products are valued in several ways, not only in terms of dollars but also in terms of less easily quantified values such as esthetics. Regardless of the values used, economic questions arise regarding the efficient allocation of forest and other resources to the production of these various products.

The absence of acceptable methods for making logical, objective choices between alternative forest management programs, each of which has associated with it varying levels and kinds of values, is a critical problem for administrators, managers, and researchers alike. A case in point is the production of game (e.g.,

deer and grouse) and timber products (pulpwood and saw logs) from aspen stands. More than dollar values are involved here. The question is: how do we use both dollar and nondollar values in making the choice between alternative combinations of timber and game products from aspen stand management?

### **Community Impact**

"Community impact" is a broad term. It relates generally to the income and employment effects of both consumption and production activities. Perhaps of more significance, however, is the embodiment of "indirect" or "secondary" effects as well as the "direct" effects in community impact analysis. The sale of aspen pulpwood by a logger to a pulp mill yields a direct income to the logger. As the logger spends his income in his local community and elsewhere, the aspen pulpwood sale results in direct income to the grocer, the power company, the service station operator, etc. In addition, as each of these direct recipients of the logger's income make sales to the logger, they respend his income for the goods and services they require to make their sales. In this way a chain reaction of indirect income and employment effects is induced.

These indirect impacts, especially those stemming from local sales of raw timber products, are frequently much larger and therefore more meaningful to local community than the direct impacts alone. In Itasca County, Minnesota, for example, the sale of \$1.00 of timber stumpage meant a total sales impact on the Itasca County economy of \$3.45 (Hughes 1970). Similar results were obtained in other studies in aspen producing areas of northern Minnesota. In some instances "community impact" maximization may be at least a short-term economic objective which is more important than maximum net return or maximum internal rate of return from timber growing.

The framework of community impact analysis can also be designed to answer various questions relating to forest environmental quality. One of these is: who gets hurt by how much? This is one of the most lively questions in forest resource management today. For example, a decision to modify (perhaps increase as well as decrease) aspen timber cut to favor wildlife production and stimulate local hunting can be evaluated at least partially within a community impact framework. The direct and indirect effects of the

increase or decrease of timber harvest can be estimated for each sector of the local economy. In addition, any change in the expenditures of hunters made locally will also have direct and indirect impact which can be estimated. This example is only suggestive of the broad range of questions involving not only the size of impact stemming from alternative forest management programs, but also the incidence of impact upon various sectors of the local economy and economies outside the local area.

For the economist, the greatest information gap for aspen management is in the area of forecasting or projections of the future. Decisions must be made concerning liquidation of aspen stocks and replacement of these stocks through regeneration and management activities. In a world of certain objectives or targets, analysis is not too difficult; but this is not the sort of world that has to be faced. Fortunately the future is not completely uncertain. Aspen consumption will be maintained for the next two decades at least and we have forest inventory data on the stands that will be used to meet this consumption.

Posterity is longer than the next 20 years, however, and 1992 and beyond will have to be faced with stock distributions that will provide flexibility for meeting long-term contingencies. Regeneration is the primary immediate need and, fortunately, aspen is one of our least expensive forest types to regenerate. Aspen regeneration has the added bonus of enhanced wildlife productivity.

The information and data that the forest manager will need to meet the somewhat indefinite planning framework outlined above is improving in a relatively rapid incremental fashion. He must incorporate it incrementally into his planning process. The areas in which information is evolving and must continue to evolve are: forest inventory, regional economic supply analysis, mensuration and stand modeling, and innovative analysis of stand treatment and utilization technologies.

The most recent applications of the USDA Forest Service forest inventory techniques can make statistical information available at all levels from the individual tree to stand and regional breakdowns. This information is needed for simulation of alternative harvesting and utilization projections on the resource base. These alternative resource base pro-

jections are the foundation for regional supply studies and in fact publication of such a study should be available soon.<sup>6</sup>

Mensuration and stand modeling in aspen have progressed significantly from the two-variable site and merchantable volume formulations beginning at age 20. Multivariate, stand development models including site, site treatment, stocking, and growth of individual stand components are becoming available.<sup>7</sup> Much of this work is developed from existing data with a minimum amount of supplemental sampling.

Innovative analysis of new technologies for stand treatment and utilization is carried on by most agencies represented at this symposium. It includes analysis in genetics, silviculture, harvesting, and manufacturing.

Needed information seems to be appearing in improved form at a faster rate than ever before. Each individual segment has its role in the aspen production framework. If anything is being neglected, it is perhaps analysis of how all of these elements fit together under the overevoked and underworked systems approach. Such an approach will involve a high degree of interdisciplinary dabbling between fields. Forestry research has had a long tradition of interdisciplinary application that can, hopefully, be maintained in an age of increasing specialization.

## CONCLUSIONS

A selective paper such as this one runs the risk of treating each topic too shallowly. It is far more satisfying to plumb the minutiae of fibre structure, economic rotations or DNA transfer in pollen. It is interesting to note that in being selectively economic in our outlook towards the paper, we have ended up being not particularly economic at all. Rather, we have dwelled on each aspect of the aspen production process as it eventually affects yield and man's basic requirements from his forest resource base.

From an economic point of view, however, we are somewhat pessimistic with respect to economic or

<sup>6</sup> Leuschner, William A. *Present and future aspen inventories in the Lake States.* (Manuscript in preparation.)

<sup>7</sup> Ek, A. R., and J. D. Brodie. *Op. cit.*

financial incentives for practicing a much more intensive level of aspen management in the near future. Unless the price of aspen wood increases significantly, implying the development of stronger and perhaps different markets, or unless costs decrease, or unless the value (measured in appropriate terms) of other products increases so that we (all of us) are willing to pay the price of foregone timber production and increased "other product" production costs, extensive management is likely to remain the rule.

Although our long-term forecast crystal ball is dark, we do see needs for improvement of information for economic analyses. These include some improvement in growth and yield data, multiple-product multiple-value decision models, and economic forecasting techniques relating to both supply and demand.

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# TRENDS AND PROSPECTS FOR WOOD PRODUCTS

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**ABSTRACT.**— Because of its excellent texture, medium density, and light color, Lake States aspen wood has an undeveloped potential for wood products. It is particularly suited for particle board, excelsior, plywood, lumber core stock, and furniture. Current utilization of the aspen resource in the Lake States is dependent upon the raw material needs of the pulp and paper industry. At least some of these needs might be satisfied as chips from residue of wood products. Further innovation is needed in the sorting and processing of the tree stems into technically superior wood components.

Because of its excellent texture, medium density, and light color, Lake States aspen wood has an undeveloped potential for wood products. It is particularly suited for particle board, excelsior, plywood, lumber core stock, and furniture. The present paper attempts to apply our current knowledge of aspen wood utilization to chart a course for expanding the use of aspen wood products.<sup>1</sup>

The problem of using aspen for its highest product value is shared by Federal, State, and corporate owners of the resource and the large consumers of pulpwood and other fiber products. The image of aspen simply as a pulping species should be changed and better use should be made of the larger sized logs.

This paper is addressed primarily to forest managers interested in the developing utilization techniques and the implications of these techniques for profitable forest production, and to pulpwood procurement people who may recognize the economic gains in sorting poplar wood for optimum utility and value.

## UTILIZATION POTENTIAL

The use and acceptance of aspen wood depends on the recognition of its properties. Aspen is similar to higher priced basswood and has a great potential

for market development. Both aspen and basswood are medium to low density woods of uniform texture and light color. For many uses they are superior to woods that have grain of distinct contrast. In small pieces, the two woods are hardly distinguishable. The uniformity of the wood structure, or lack of distinct grain, makes aspen desirable for uses where coarse grain would interfere with machining, gluing, or wearing qualities. The uniform wood structure of aspen is readily adaptable to various finishes.

The uniformity of aspen wood structure also makes it uniquely adaptable for particle board production in which the design of the particle such as a flake, is critical to the properties of the board. The formation of a "designed" flake is much more difficult with a grainy wood. The relatively low density of the aspen particle allows intimate contact under pressure and contributes to the effectiveness of both the adhesive bond and product strength. For complete treatment of the wood technology of the poplars, reference is made to the work of Lamb (1967) and Kennedy (1968).

## SORTING FOR BEST USE

In order to maximize aspen utility and value, pulpwood procurement people must be willing to investigate methods of sorting out high-value bolts. Sorting the higher value sawbolts and veneer bolts during harvest, or at a concentration yard, could increase the average stumpage value and at the same time make the smaller pulpwood sticks available to the pulping

<sup>1</sup> For a full treatment of aspen utilization potential see the *Lake States Aspen Reports*. *Lake States For. Exp. Stn.*, 1 to 22, 250 p., illus. 1947 to 1951.

industry at a reduced price. Of course this reduction will need to be balanced against a possible reduced pulp yield. A sign of the times about integrated timber use is the diversion of selected logs from a pulp mill woodroom to a stud mill at a western Canada location as described in a recent trade journal. Chips and residue from the sawing and veneering operations would be a further incentive in the sorting of stand-run poplar.

Optimum utilization of aspen trees, as with other hardwoods, should begin with bucking the tree stems. Yet there appears to be no appreciable aspen operation in the Lake States where log quality is considered in bucking lengths of logs or bolts. Presently, grading for various uses depends upon describing 100-inch bolts of various qualities. The traditional 100-inch bolt is dictated by handling factors for pulpwood, and is not especially well adapted to products of higher utility.

Tree-length logging and hauling would help maximize aspen utility and value. At a concentration yard the poplar stems could be cut into lengths according to product. Saw and veneer bolts could be separated from pulpwood on the basis of diameter and graded by number of "clear faces" (quarters), straightness, and bolt-end characteristics. After quality bolts for lumber or veneer are sorted out, the residual bolts could be shipped as pulpwood or chipped on site for shipment to pulp mills. Manufacturing residue would also be used.

At present some aspen saw and veneer bolts are sorted from pulpwood operations if there is a demand to justify the sorting costs. Yet much aspen suitable for veneer or lumber is converted to pulp. Rarely is stand-run poplar suitable exclusively for a sale of sawtimber. Large pulp users tend to be conservative about sorting out aspen for lumber or veneer use and changing methods of measurement. Now that weight scaling is being accepted, there should be no more problem in converting from tons of cordwood to tons of chips, board feet of lumber, or square feet of veneer than from cords or other units.

A trend toward separating aspen bolts for lumber and veneer products has been greatly aided by the use of hydraulic cylinders in logging equipment. The self-loading truck and the "clam" attachment on skidding equipment enables some loggers to "bunch"

bolts of different quality and to load them for different destinations. Large, specially designed machines and conveyor systems are available for handling and sorting roundwood at concentration yards.

## LUMBER PROCESSING

An important anatomical feature pertinent to sawing small logs is "juvenile wood," the wood in the region of the center or pith. Its peculiar cell structure and properties result in relatively high longitudinal shrinkage. Juvenile wood on one edge or side of a board can cause bowing or crooking when the board dries. Because aspen is generally a small tree juvenile wood may be expected to occur frequently.

In sawing poplar the bolts should be cut so that the pith or heart is "boxed" and does not occur on the side or edge of a board. This is particularly important in cutting long products such as studs which may crook badly. Improved sawing and drying techniques have been developed that are expected to stimulate wider use of aspen for studs and other structural material.

For Lake States poplar a highly automated sawmill is needed that cuts narrow slabs parallel with the bark, conserving the clear wood and leaving wedge-shaped residue cuttings from the center of the bolt. Most of the juvenile wood and center decay could then be chipped. The question of how acceptable these chips would be at the pulpmill remains a matter of pulping research and economics.

Presently, most poplar lumber is sawn on conventional sawmill equipment, usually with circular saws of heavy kerf. The disadvantage to a small diameter log is obvious. A few gang saw operations for aspen bolts have been successful. A recent study of sawing methods has confirmed that when dimension stock cuttings are the end products in a sawing operation, sawing logs or bolts "live" can yield more clearcuttings than conventional turning to remove the high quality "jacket board" on all sides (Bousquet and Flann 1970). Such findings should be considered in the design of a specialized sawmill for poplar bolts. So-called "stud mills" have been proposed for cutting small timber such as aspen. Production costs may be low but the maximum product value may not be realized unless quality is maintained.

## LUMBER USES

Because of its small size, aspen timber has had some difficulty entering the general lumber market. Its close relative, cottonwood, is recognized in the national lumber trade because it is available as large saw logs in 12- to 16-foot lengths. Aspen is normally produced in 8-foot lengths even in the larger diameters. The larger logs have become known commonly as "box bolts" because the lumber has been readily accepted by wood container manufacturers. The wood is strong enough to be used for containers of relatively low weight. Its light color gives a clean appearance and allows label printing. An added attraction for reusable boxes is its ability to wear well without slivering. Because it lacks odor when dry, aspen is the standard wood for cheese box heading in the Lake States. The strong competition of the corrugated paper container has been a depressing factor in the wood box industry.

A considerable amount of aspen, grown within easy trucking distance of metropolitan areas, is sawn into lumber for crating. In the Lake States where pine is milled for light construction lumber, some poplar has been produced as standard 2 by 4 studs for house walls. Carefully manufactured, dried and graded aspen has been shown to be adequate for this use.

The uniform structure, medium density, and good gluing properties make poplar wood particularly suited for core stock. It may be overlaid with thin veneers or other surface material without contributing to "telegraphing" when pressed in the gluing operation. With modern mechanized edge-gluing equipment, aspen dimension stock cuttings as narrow as about 1½ inches may be used in this product. Random-width cuttings are obtainable from the small logs typical of poplar.

The utilization of poplar lumber for cabinetry and furniture is a small, but growing industry in the Lake States. Here again, uniformity of structure and good strength-density relationship are plus factors. Poplar presents a subdued grain surface that is adaptable to a variety of hardwood finishes. Machining aspen wood for uses such as furniture parts is no more difficult than machining many of the conventional furniture woods, but it requires careful consideration of machine-setting and knife grinding. Figure 1 shows a furniture group produced from poplar.

In many of its properties, poplar is similar to the soft western pines. Lake States aspen has been used successfully in the experimental production of louvres and window sash. But lack of sufficient lumber in comparison with western pine prevents wider use of poplar for high volume products such as window sash.

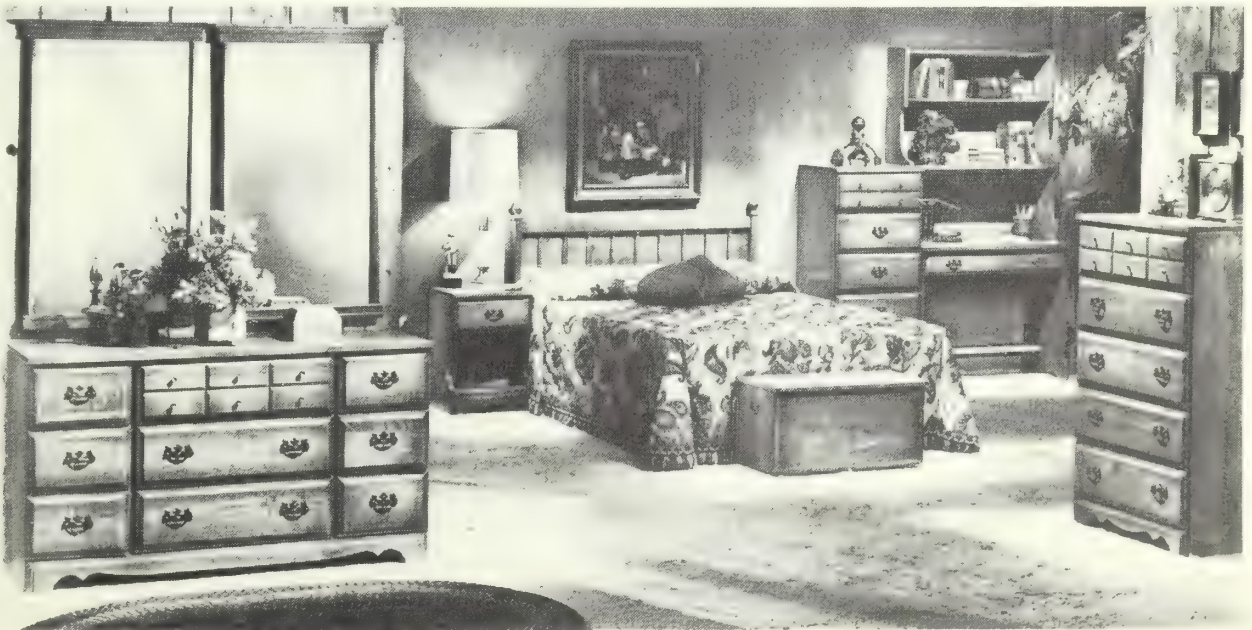


Figure 1.—Suite of hardwood furniture produced in Iron Mountain, Michigan. The hardwood used here is poplar. This is an outstanding example of the utilization potential of the wood.

## PLYWOOD

Although poplar plywood production has become well established in Canada, there is only a single aspen veneer and plywood plant in the Lake States. Yet the product has found acceptance in a market that has been dominated by West Coast woods and, more recently, southern pine. A key to this development has been the adaptation of special manufacturing equipment for small diameter bolts. The properties of poplar wood are uniquely suited for plywood in many applications. Its uniformity of structure has made it well established as a base for overlaying thin sheet materials. It is a preferred wood for matches made from veneer. Further progress in the mechanization of joining veneer sheets, both edgewise and endwise, could lead to the acceptance of relatively small, clear, poplar veneer bolts, and make raw material more available.

## EXCELSIOR AND PARTICLE BOARD

A market for aspen excelsior wood is well established in the Lake States. Uniformity of wood structure makes for uniformity of the excelsior strands and uniformity of product. Innovative engineering and usage can lead to an expansion of markets. Some traditional uses for excelsior have been displaced but excelsior padding is still unique in absorbing shocks.

Excelsior has recently been used as a roadside binder. The strands have a special ability to attach to soil particles. A developing use for excelsior is in evaporator pads for humidity and temperature control equipment. Poplar has displaced basswood as the favored wood for excelsior because of the superior mechanical properties of its strands. Fire-resistant structural panels, made from excelsior with Portland cement or other inorganic binders, have been used as structural products. The uniformity of aspen wood structure helps create a panel product of uniform properties. The entire roof of the Forestry-Institute of Wood Research building at Michigan Tech is composed of excelsior board spanning laminated wood beams.

Much experimental work has been done on aspen for particle boards. Again, aspen's uniformity of structure makes it possible to design a particle of constant properties. Although much of the particle board industry uses non-uniform or hammer-milled particles,

some boards with designed-flake particles are produced that have unique structural properties. Aspen flake board production has been successfully introduced in Canada and is being expanded in the Lake States. A specialized particle board designed as an exterior panel is now in production in Minnesota. Further technical progress in the design of flakes and their orientation in board formation may be expected.

## THE WOOD IS "POPLAR"

The use of "aspen" and "poplar" interchangeably and alternately in this paper is purposeful. To gain acceptance as a wood of good technical qualities comparable to basswood, the lumber we know as "aspen" (trembling aspen and bigtooth aspen) should be identified as "poplar," from the botanical names *Populus tremuloides* and *Populus grandidentata*. The demeaning term "popple" should be avoided. As Garland (1946) suggested, the wood might be called white poplar to distinguish it from the yellow-poplar available in the lumber market from the southern United States. It is of interest that yellow-poplar was probably so named by early settlers because the wood of the tuliptree has the same low density and uniform texture that they associated with the true poplars in Europe. One Lake States producer of aspen lumber and dimension stock already uses the name "northern poplar." Leadership in improving the image of aspen wood products should be shared by those foresters charged with the management and improvement of the large Lake States timber resource.

The Canadian industry and agencies have wisely grouped the woods of most species of *Populus* under the common name "poplar" (Kennedy 1968). The Forest Products Laboratories Division, Canadian Forestry Branch, has given priority to the common name "poplar" (Jenkins 1951). However, the U.S. Forest Products Laboratory (USDA Forest Service 1955) uses the term "aspen," but indicates that "poplar" or "popple" is in fairly common use in trade practice in the United States.

## CONCLUSIONS

We can expect the use of aspen wood products to increase because aspen is relatively abundant and it has characteristics that make it suitable for a variety of products.

Although the pulp and paper industries will continue to be important consumers of aspen, improved appreciation of aspen wood products should divert more aspen logs into use for higher value products. This trend is already evident, of course, but improved technology in veneer and lumber utilization may be expected to make harvesting aspen for an integrated market the accepted practice.

This will mean that suitable logs will be sold to veneer mills where these are available. Other large logs will go to dimension stock plants where primary products will be parts and panels for furniture and cabinets. Secondary products may be pallet parts, box shook, structural lumber, or crating material. Only the smaller roundwood would be used for pulp chips or particle board.

Historically, the paper industry has been able to adapt itself to progressively less critical raw material specifications through research and development. Chips and residue from manufacturing processes will supplement the traditional pulp to an increasing extent.

Improved utilization technology will help to offset the present aspen surplus. At the same time the increased demand for higher quality will present a new challenge to timber management research.

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# TRENDS AND PROSPECTS FOR USE IN FIBER PRODUCTS

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**ABSTRACT.**—About 85 percent of the operating pulpmills in the Lake States use some aspen. In recent years the aspen percentage has varied between 45 and 50 percent of all pulpwood use. Pollution abatement orders may result in some changes in pulpwood use. Aspen has good credentials for use in fiber products. It is light colored, making its use for groundwood pulp attractive. It is readily pulped by any of the commercial processes, and is a raw material most often used in process developments because it is easily pulped. Aspen fiber morphology is excellent. The length-to-diameter ratio and the thin-to-medium-thick walled fibers are particularly suited to enhancing fine paper structure. Its low density is attractive to fiberboard production. The relative low yield per unit cost for aspen probably restricts potential expanded use.

Within the past 25 years we have seen a tremendous increase in the use of all types of hardwoods for fiber product manufacture. While a cost advantage may have been the first and perhaps still is the foremost incentive, certain quality gains were realized so that today hardwood fibers are essential to the satisfactory performance of many fiber products.

In the northern United States aspen has since the early 1940's been the major factor in the remarkable growth in hardwood consumption for pulping.

Recent statistics on aspen use in the Lake States illustrate its importance and availability. Nearly 85 percent of the pulpmills operating in this area use some aspen, and this use comprises some 45 to 50 percent of all the pulpwood consumed (table 1). This speaks well for aspen's use in fiber products since it is estimated to make up about 30 percent of the timber volume.

We are all aware that pressures for pollution abatement are causing wide-scale reevaluations by the fiber products industry. It is too early to attempt to analyze what this may mean for aspen.

Aspen and poplar species in general have been the subject of extensive research throughout the world (Brown, Seager, and Weiner 1957; Roth and Weiner 1964, Weiner and Roth 1970). Much of this research is related to growth, but the general ease in processing and the quality of the resulting fibers and fiber products have made these species somewhat of a standard in the control and evaluation of new products and processes.

## WOOD PREPARATION

When aspen first entered pulpwood markets, most was sap-peeled in the woods before shipment. In recent years, preparation has changed dramatically and many pulpmills now practice "hot logging," debark at the mill, and store a limited time. Perhaps the most important factors in the change were the general rise in storage costs and a significant brightness loss resulting from extended storage of peeled logs. Prolonged storage is still practiced when the wood is used in the sulfite or bisulfite process for alleviating potential pitch problems. Other factors were the limited labor market and the lack of accepted portable debarkers. Today we find year-round harvesting and preparation operations for aspen with debarking both in the woods and at the mill.

For debarking at the mill site, mechanical and

<sup>1</sup> Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Table. 1 — *Lake States pulpwood production*  
(In thousands of rough cords)

Kind of pulpwood	1965	1967	1968	1969	1970
Hardwood					
Aspen (roundwood)	1,780	1,976	1,753	1,963	1,966
Other miscellaneous (roundwood)	444	539	449	555	658
Residues	8	195	219	259	302
Softwood					
Roundwood	1,268	1,235	1,091	1,139	1,313
Residues	31	20	39	27	46
Total production	3,531	3,965	3,551	3,943	4,285
	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>
Aspen	50	50	50	50	46

drum debarkers or combinations thereof are used. Wood cut and delivered during the sap peeling season cleans up quite satisfactorily in one pass, but multiple passes are required for tight-bark seasons. Some operators have found that series installation of debarkers has advantages over recycle systems.

Portable debarking equipment has been added to some woods operations and concentration yards away from the mill site have been developed. New forestry and harvesting practices for optimum management of our wood resource will no doubt force a growth in these types of systems (Benson and Peckham 1968).

Whole tree utilization has potential in the fiber products field. Bark-chip separation techniques will be required for some products. Various methods are under investigation and it is expected that alternatives will be available for both the processor and the user of the wood.

Aspen, when improperly debarked, has been known to cause some operating problems. Perhaps the most troublesome of these is the filling of paper machine wire caused by deposits of stone cells from the inner bark on the wire, a problem similar to the filling caused by resinous woods.

## PULPING BY COMMERCIAL METHODS

Pulping, the separation of wood into fibrous elements, is accomplished by mechanical means, by

chemical removal of the lignin and incrustants, or by combinations of these two procedures. In each case, the pulp characteristics needed for a particular wood fiber product along with economic considerations determine the choice of the process — groundwood, chemimechanical, semichemical, sulfite, or kraft.

Aspen is readily pulped by any of these commercial processes (Brunson 1964). In fact, it is the wood most often used in development work because of the general feeling that if you cannot pulp aspen with the technique under development, you most likely do not have a viable plan or program. Processing conditions are not uniform from mill to mill for any of the processes, but can be controlled at an optimum for each pulp and fiber product situation. For the optimum, a wood specification such as percentage of rot, size, brightness, or other wood factor could be included. Table 2 gives estimated pulp yields of different species for each of the commercial processes.

The data demonstrates quite clearly the yield advantages of the higher density woods and the importance of including cost in the calculations so that yield per unit cost can be the comparable unit.

## Groundwood

Two procedures are available for producing groundwood pulps, which in 1970 accounted for almost 4½ million tons of production in the United States, of which aspen approached 10 percent.

Table 2. — *Estimated yields of pulp for various wood species*

Species	Pulping processes						
	Ovendry	Semichemical					
	wood	Groundwood	Chemimechanical	80 percent	60 percent	Sulfite	Kraft
				yield	yield		
	Lbs./cord	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton
Aspen	1,825	1.08	1.15	1.31	1.62	1.88	1.97
Black spruce	1,990	.99	1.06	--	--	1.90	1.96
Hemlock	1,990	.99	1.06	--	--	1.95	2.05
Southern pine	2,405	.83	--	--	--	--	1.66
Birch	2,490	--	.85	.96	.83	1.46	1.39
Beech	2,905	--	.76	1.18	1.02	1.54	1.41

The conventional stone grinding process involves holding logs under specified pressures against a rotating grinding wheel of a designated grit size, structure, and surface pattern. Bundles of fibers, individual fibers, and parts of fibers are separated from the log and further ground to form a pulp of desired fiber size distribution and strength. Low-density woods such as aspen are best suited to this process for the production of optimum groundwood quality (Hytinen, Martin, and Keller 1960; Perry and Canty 1971).

In recent years, a second method for groundwood pulp manufacture has come into significant use. This is the refiner groundwood process which developed primarily as a result of the availability of chips from sawmills or other residue sources (Allan, Skeet, and Forgacs 1968). In this process, the wood chips are reduced to fiber and fiber fragments by refining in a series of attrition mills, commonly called disc mills. The resulting pulps are known by a variety of names — refiner groundwood, disc woodpulp, super groundwood (Richardson and Le Mahieu 1965), and others.

Although the two groundwood pulps are used in similar paper grades, the refiner pulp is usually superior in both tear and bonding strengths, has more long fibers, is poorer by varying degrees in opacity and brightness factors, and usually requires the papermaker to adapt his machine to a change in runnability.

Aspen groundwoods can produce the paper with highest printing quality of any groundwoods and their somewhat lower strength does not materially affect runnability factors on either the paper machine or the printing press.

## Chemimechanical

Chemimechanical pulps are the result of a very mild chemical action to delignify and soften wood chips for subsequent refining in a disc mill (Leask 1968) at yield ranges of 80 to 95 percent. Steam-treated pulps characterized by those from the Masonite and Asplund process are included in this category.

The chemical and steam treatments or combinations of the two permit more effective fiberizing and also allow the use of the higher density hardwoods. Certain physical properties are enhanced. These pulps have some use for fine paper but are most used in coarse papers and in many kinds of fiberboard (Fahey and Steinmetz 1971). In this latter category, the low density of aspen is an advantageous factor, especially for the low and medium density fiberboard field. Growth rate in the fiberboard market approaches 10 percent per year.

## Semichemical

Semichemical pulps (Vamos, Lengyel, and Mero 1964; Van Eychen 1968) differ from the chemimechanical types by yielding less — 60 to 80 percent. The chemical treatment is somewhat more severe and the subsequent fiberizing requires less power. Some 3½ million tons of semichemical pulps were produced in the United States in 1970 using all types of hardwoods but with negligible aspen use.

Aspen pulpwood, however, is suitable for this process and the resulting pulps are usable in both fine and coarse paper. Almost all of the semichemical pulp tonnage goes into coarse paper grades where the yield per unit cost advantage of the higher density hard-

woods limits aspen use. In the fine papers, kraft and sulfite pulps are preferred.

### Sulfite and Kraft

These processes together with bleaching delignify pulps completely and make them suitable for fine paper. The aspen pulp fibers resulting from these processes have special quality characteristics that make them particularly suitable for fine paper structure. They have thin- to medium-thick walls and a length to diameter ratio in excess of 30. While vessel elements are numerous, their diameter is well below that which results in the well-known and disastrous fiber pick problem associated with printing papers containing oak pulp. Thus the fine papermakers, especially those using sulfite pulps, have good reasons to want aspen in their wood procurement plan.

### OTHER PULPING METHODS

New pulping methods arise from laboratory and pilot investigations but usually fail to replace those just presented for economic or pulp quality reasons, or both.

Solvent pulping is routinely offered for consideration as a commercial process. A goodly number of solvents together with a hydrolysis reaction will remove lignin from wood, but the processes remain unattractive despite steady promotion in isolated cases.

In general, the commercial potential for new pulping methods must be judged on the basis of the quality obtainable in relation to present methods and the pollution abatement technology economically available for these processes.

It is highly probable that if and when a new pulping process is put through the paces of pilot planting and commercial evaluation, aspen pulpwood would be one of the first wood species to be used.

### SUMMARY AND CONCLUSIONS

In summary then, we know that aspen is available and is readily pulped by any of the commercial processes now in use. This fact strongly suggests that if and when pulping processes are changed, aspen will still be a readily usable source of pulp.

The bulk of the aspen pulpwood produced in the Lake States is used in the groundwood, chemimechanical, and sulfite processes. Aspen pulp in these processes provides the pulp quality needed at an economic advantage over other species.

The groundwood pulps are used mostly in printing paper grades. Here aspen provides highest printing quality and opacity without sacrificing runnability on either the paper machine or printing presses. The publication paper segment of the industry recently suffered production cuts but should recover with the general business upturn expected. Small quantities of aspen groundwood are used in tissue at some expense in quality but with economic advantage. This must never be considered a significant outlet.

Chemimechanical pulps are used principally in fiberboards and to a very limited degree in fine papers. In fiberboard, the low density of aspen is an important factor for the low and medium density products. The fiberboard market is expanding at a 5 to 10 percent rate per year.

Aspen is used in sulfite pulpmills for the production of pulps for fine paper grades. Sulfite pulping, however, is in decline and such mills are being shut down. Modifications of sulfite pulping with recovery systems are operating and planned for the Lake States. The real future of this outlet, however, is still cloudy and unpredictable.

Therefore aspen must look to groundwood and chemimechanical pulping for its future. Its advantageous fiber morphology, as shown on table 3, makes it a desirable wood fiber, but its low density is a serious economic disadvantage that limits expansion to other processes and paper grades.

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Table 3.—*Physical and chemical characteristics of five pulpwoods*<sup>1</sup>

Species	Morphology							Cellulose	Lignin	Hemi-cellulose	Density
	Fiber	Vessel	Fiber	Wall	Fiber	Vessel	Ray				
	:length:	:length:	width	:thickness:	:volume	:volume	:volume				
	Mm.	Mm.	Microns	Microns	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Aspen	0.95	0.55	18-40	2.2	53	33	14	53	16	31	22
Birch	1.20	.95	20-36	2.8	66	21	11	41	19	40	35
Maple	.70	.35	16-30	2.8	61	21	18	41	24	35	35
Spruce	3.20	--	28-40	2.9	93	--	6	44	28	28	24
Southern pine	3.50	--	35-45	3.8	90	--	10	41	29	30	30

<sup>1</sup>/ Sources of data: Forest Products Laboratory, Rydholm (1965), Joint Textbook Committee of The Paper Industry (1969), Marton and Alexander (1964).

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# WOOD AND FIBER PRODUCTION FROM SHORT ROTATION STANDS

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**ABSTRACT.** — Growing native and improved aspen on short rotations is recommended. Information on young sucker stands indicate that by using short rotations of 10 to 20 years and complete tree, chipping-in-the-woods harvesting, total annual volume production can be more than doubled. Additional major increases in volume production can be expected through the use of genetically improved trees, fertilization, and irrigation. Wood and pulp quality are expected to decrease only slightly from large-scale use of short rotation aspen.

For a number of years I have had the philosophy that "competition," not love, makes the world go around and I think that this concept will particularly apply to Lake States forestry in the 1980's and 1990's. Forests, as a source of woody raw material and forest management as many of us know it, will survive in the Lake States region only if we remain competitive. A major increase in both hardwood and conifer requirements is predicted. Hardwood needs, for example, are expected to increase by 400 percent by the year 2000 (USDA Forest Service 1965a). I am not naive enough to believe that we can grow red pine and jack pine rapidly enough to compete with southern pine and increase our share of that market, but I do feel that there is a possibility that we can remain competitive in producing hardwood fiber, particularly aspen.

The solutions most often suggested for meeting our raw material requirements include improved utilization, intensive forestry, and the use of genetically improved trees. The concept of short rotation aspen forestry encourages the use of all three approaches and for this reason is obviously not new. The objective of this paper is to present you with data indicating that a system of short-rotation forestry will work.

## SYSTEM REQUIREMENTS

To make a short rotation cellulose system economically and biologically feasible requires the use of species that: (1) reproduce easily, (2) exhibit rapid

juvenile growth, (3) have form and natural pruning that facilitates mechanical harvesting, (4) will respond to intensive management practices, and (5) have suitable juvenile wood and pulp quality. Such a system also requires an efficient method of harvesting and complete utilization of small-size trees.

## SILVICULTURAL CHARACTERISTICS

The silvicultural characteristics of Lake States aspen, bigtooth and quaking aspen (*Populus tremuloides* and *P. grandidentata*), is well documented (USDA Forest Service 1965b). Aspen, particularly quaking aspen, is widely distributed geographically and has the ability to grow on a wide variety of upland soil types. Growth and development of aspen is strongly influenced by soil conditions, and aspen and aspen hybrids are expected to respond to intensive silvicultural procedures aimed at improving site quality. Noted for its vigorous production of root suckers, aspen rapidly occupies an area after being cut and develops into densely stocked stands containing trees with good straightness, good natural pruning, and narrow crowns. Also of considerable importance is the ability of aspen stands to develop, once established, with a minimum of silvicultural treatment.

## SUCKERING AND VOLUME GROWTH

Rapid volume growth is essential to any short rotation system. In the case of aspen, the key to the rapid growth of juvenile stands is the vigorous suck-

ering of aspen and its ability to completely occupy a site within 2 to 3 years after harvesting. Sucker numbers, the first year after cutting, may run as high as 40,000 stems per acre. Rapid thinning occurs but stem numbers may still be as high as 14,000 at age 6, 8,000 at age 9 and 2,200 at age 23 (table 1). Height growth is normally rapid and is influenced by site quality. Diameter growth is usually quite slow but because of the large numbers of stems per acre, total volume growth is considerable.

The average volume growth for commercial forest lands in the Lake States region is estimated to be only 22 cubic feet/acre/year (USDA Forest Service 1965a). Published total volume growth data for aspen stands less than 20 years of age are extremely scarce. Information available indicates volume growth from unmanaged young sucker stands varies from 25 to 106 cubic feet per acre per year (table 1). Site quality on these stands ranged from poor to medium (estimated age 30 site index from 30 to 50); aspen growing on the better hardwood sites were not included. There is considerable evidence to show that by completely utilizing young aspen sucker stands (age 15 to 20 years), the harvested volume/acre/year will be approximately double the volume obtained by a conventional pulpwood harvest at age 40 (Benson and Einspahr 1972). The increased production appears to be due to rapid juvenile growth, complete utilization, utilization of virtually all the trees on an area, and the salvaging of volume growth that

normally would be lost to disease and insects.

Under certain management situations it may be desirable to plant genetically improved aspen. To use improved aspen in the described coppicing system, it is recommended that improved seedlings be planted at wide spacings (minimum of 80 square feet per tree). After 5 or more years, the planting could be cut back and in this way a sucker stand of the most vigorous clones established. Good volume growth is being obtained from plantings of some of the better materials presently available (table 2, fig. 1). The data illustrate the influence of age and spacing on total volume growth of young aspen plantings and indicate some of the alternatives available to the forest manager when establishing improved aspen. Suckering data on several of the materials listed in table 2 indicate that, after 8 years, annual volume growth on the first rotation of suckers will be 10 to 30 percent better than for the original planting (fig. 2).

Preliminary growth chamber studies with aspen seedlings and field studies involving both seedling and young sucker stands indicate moderate growth response (15-30 percent) can be expected from fertilization treatments. In those situations where it is feasible to both fertilize and irrigate, volume growth increases in excess of 100 percent appear possible (Einspahr *et al.* 1972a).

Table 1.—*Age, trees per acre, and volume of unmanaged young sucker stands*

	:	:	:	Total volume	:	Average volume growth
Location	:	Age	:	Trees per acre	:	per acre per year
		<u>Years</u>		<u>Number</u>		<u>Cu. ft.</u>
						<u>2/</u>
						<u>Cds.</u>
N. Wisconsin		6		14,463		151
N. Wisconsin		9		8,659		272
N. Wisconsin		12		1,900		650
Manitoba		13		7,695		1,373
Manitoba		14		5,990		830
N. Wisconsin		15		2,200		1,379
N. Wisconsin		18		1,700		1,770
Manitoba		19		2,464		1,240
Manitoba		23		2,226		2,082
						25
						30
						54
						106
						59
						92
						98
						65
						91
						0.29
						.35
						.64
						1.25
						.69
						1.08
						1.15
						.76
						1.07

1/ N. Wisconsin data from The Institute of Paper Chemistry, 13-year-old Manitoba data from Bella and Jarvis (1967) and the 14-, 19-, and 23-year-old Manitoba data from Steneker (1964).

2/ Based on 85 cubic feet per cord.

Table 2. — *Age, density, and volume of improved aspen in plantations*

Type <sup>2/</sup>	: Age :	: Trees per acre :	: Total volume : per acre :	: Average volume growth per acre per year <sup>3/</sup>	
	Years	Number <sup>4/</sup>	Cu. ft.	Cu. ft.	Cds.
Triploid hybrid aspen (2)	5	538 (9x9)	76	15	0.18
Quaking aspen progeny (14)	5	2,420 (3x6)	211	42	.49
Quaking aspen progeny (2)	10	538 (9x9)	503	50	.59
Triploid aspen (1)	10	538 (9x9)	613	61	.72
Quaking aspen progeny (7)	10	1,210 (6x6)	1,075	107	1.26
Triploid hybrid aspen (2)	10	538 (9x9)	1,118	112	1.32
Quaking aspen hybrid (1)	10	538 (9x9)	1,300	130	1.53
Bigtooth aspen hybrid (1)	10	538 (9x9)	1,905	190	2.24
Triploid aspen (1)	13	538 (9x9)	1,361	105	1.24
Triploid hybrid aspen (2)	13	538 (9x9)	2,577	198	2.33

1/ Test plantings have been adjusted to a standard 90 percent survival to make comparisons possible. Since actual survival for most was over 90 percent, the growth figures are conservative.

2/ Number of progeny groups averaged is in parentheses.

3/ Bark-free volume growth; based on 85 cubic feet per cord.

4/ Spacing in feet given in parentheses.

Figure 1. — *A triploid hybrid aspen planting that at age 13 has a mean annual increment of 198 cu. ft./acre/year. The planting is growing on a sandy soil in northern Wisconsin.*





Figure 2. — *Eight-year-old triploid hybrid suckers that have a mean annual increment of 120 cu. ft./acre/year. The sucker stand is growing on a sandy site in northern Wisconsin.*

## WOOD QUALITY

Specific gravity, fiber length, and levels of lignin and extractives are important when considering wood as a raw material for papermaking. Characteristically, juvenile wood has less desirable wood properties than mature wood and the wood of aspen is no exception. The question then becomes, at what age do the overall wood properties improve to the point that the wood is suitable for use by the pulp and paper industry? Table 3 summarizes wood quality data from several studies involving juvenile aspen, and table 4 provides tentative estimates of wood quality/age relationships for quaking aspen. Slight specific gravity decreases and modest fiber length increases have been observed on rapidly growing aspen. The trends given in table 4 are for native sucker stands growing at average growth rates. Specific gravity appears to be little influenced by tree age

in trees from ages 5 to 30 years. Tree-to-tree variation within age classes appears to be as great as the differences observed between trees of different ages.

Fiber length, on the other hand, appears to be strongly influenced by age and location within a tree (Einspahr *et al.* 1972b). Observations made on aspen pulps from numerous sources indicate that pulp from age 5 trees will have approximately 40 percent shorter fiber length than age 30 trees (table 4). Ten-year-old trees are expected to have fiber length about 80 percent of normal and by age 15 it has been estimated that pulp fiber length will be only 8 to 10 percent shorter than at age 30. Genetic improvement of fiber length has been one of the goals of aspen tree improvement work. Triploid hybrid aspen presently available have at age 10 pulp fiber lengths greater than 30-year-old native aspen. Use of such materials would make possible shortening the rotation age without any loss in fiber length.

Levels of lignin and extractives are important because they provide estimates of maximum possible pulp yield and suggest, in the case of extractives, possible paper machine pitch problems. Lignin levels in young aspen are consistently less than those for mature aspen, but overall differences between age 10 and age 30 are relatively small (18 vs. 19 percent) (table 4). Five-year-old aspen often exhibit high levels of extractives but by age 10 extractive levels appear to be near normal. At rotation ages of greater than 10 years, no extractive problems are anticipated.

## PULP QUALITY

Pulp quality of juvenile aspen has also been investigated, although not as extensively as wood quality. The amount and type of pulping data available for review has resulted in a less well-defined "age" relationship than was evident for wood properties. Pulp yield, based upon age 5 micropulping information, indicates yield of extremely young aspen will be as much as 4 percent lower (48 vs. 52 percent) than 30-year-old aspen. Ten-year-old diploid aspen,

Table 3.— *Variation in quaking aspen wood quality*

Source and type data	Tree age	Specific gravity	Fiber length : wood <sup>1/</sup>	Lignin	Extractives
	Years		Millimeters	Percent	Percent
Aspen Heritability Study <sup>2/</sup>					
1958 plantings	5	0.37	0.63 (3-5)	18.5	3.7
1959 plantings	5	.37	.63 (3-5)	17.9	4.7
1960 plantings	5	.37	.59 (3-5)	17.8	4.2
Micropulping Study <sup>3/</sup>					
Diploid families	5	.37	.53 (5)	17.8	6.8
Triploid clones	5	.36	.61 (5)	17.2	6.3
Triploid hybrid families	5	.40	.70 (5)	17.2	5.4
Fertilizer/Irrigation Pulping <sup>4/</sup>					
Control	9	.33	.66 (7-9)	17.5	1.5
Fertilizer (F)	9	.33	.68 (7-9)	17.4	5.4
Water (W)	9	.32	.72 (7-9)	17.6	2.4
F + W	9	.30	.68 (7-9)	16.7	4.9
Whole Tree Pulping Study <sup>5/</sup>					
Diploid families	10	.35	.86 (9-10)	18.0	3.4
Triploid clones	10	.34	.96 (9-10)	18.4	3.3
Triploid hybrid families	10	.42	.99 (9-10)	18.0	3.5
Mature diploid	33	.35	.97 (30)	18.9	3.4
Whole Tree Clonal Study <sup>6/</sup>					
Mature diploid	30	.40	.87 (30)	--	--

1/ Fiber length based upon annual rings indicated by the numbers in parentheses.

2/ Einspahr *et al.* (1967).

3/ Einspahr *et al.* (1968).

4/ Einspahr *et al.* (1972b).

5/ Einspahr *et al.* (1970).

6/ Buijtenen *et al.* (1962).

Table 4.— *Estimated wood quality/age relationships*

Tree age (years) :		Specific gravity <sup>1/</sup> :	Fiber length :		Wood <sup>2/</sup> :		Lignin :	Extractives :
		Percent	Mm.	Percent	Mm.	Percent	Percent	Percent
5	0.37	97	0.50	57	0.73	69	17.7	5.2
10	.37	97	.71	82	.85	80	18.0	3.5
15	.37	97	.80	92	.94	89	18.2	3.5
20	.38	100	.85	98	1.00	94	18.5	3.4
30	.38	100	.87	100	1.06	100	19.0	3.4

1/ Specific gravity estimates based upon b.h. disk samples, dry weight ÷ green volume. Percentages were obtained by calling age 30 trees 100 percent.

2/ Values taken from fiber length/age curve prepared from b.h. wood samples. Percentages were obtained by calling age 30 trees 100 percent.

based upon limited data, are expected to have pulp yields about 2 to 2½ percent lower than 30-year-old aspen. The yield of puckerbrush chips (Chase *et al.* 1971) of unknown tree age was lower than that of the other studies reported and appears, in part, to reflect differences in cooking conditions and type of chip sample employed.

Zero-span tensile strength, which is considered a measure of fiber strength, appears to be about the same for young aspen as for mature aspen. Tear, burst, and tensile strength (breaking length) seems to have been little affected by tree age. Although based upon a limited amount of data, it appears that pulp of 10-year-old trees can be used successfully to replace pulp from mature aspen. Chase and his associates (1971) drew similar conclusions in their study of Maine aspen puckerbrush chips.

## HARVESTING AND DEBARKING PROBLEMS

Important to the short rotation concept is the availability of an efficient method for harvesting and debarking small-sized trees. The method most often suggested is to chip the material in the woods and then segregate the wood and bark mixture after chipping. Such a procedure is already a reality and makes it possible to utilize the entire stem plus branches and also allows the bulk handling of the chips from the woods to the mill. Recent "chipping in the woods" demonstrations in northern hardwoods have added considerable impetus to the short rotation concept (Paper Trade Journal 1971). The harvesting system employs a feller buncher, skidders, and a high capacity truck-mounted chipper. The system essentially doubles the yield of wood chips from an acre of northern hardwood land by utilizing "nonmerchantable" trees and by utilizing all trees more completely. Production rates in excess of 400 tons (green weight) of chips per 8-hour day are attained with a 6-man crew. The rapid rate of production is the result of chipping the trees prior to debarking and the ability of the chipper to handle multiple stems. Additional technological advances are expected which will put the short rotation concept in an even more favorable economic position.

Bark, a perennial problem to the forester and papermaker, offers an interesting challenge to short rotation forestry. Research on aspen wood/bark separation and segregation indicates that aspen bark may

well be one of the easiest to handle and can be separated by several different techniques. One approach is to pulp the bark right along with the wood (Chase *et al.* 1971). Another approach is the use of the compression debarking technique developed by Blanchard<sup>1</sup> and described by Blackford (1961, 1965) and recently modified and demonstrated by the North Central Forest Experiment Station's Forest Engineering Laboratory in Houghton, Michigan. Still another promising approach is a water flotation procedure described by Einspahr *et al.* (1968) that depends upon specific gravity and moisture content differences between bark and wood to cause segregation of bark and wood mixtures. Also very promising is the procedure described and patented by Lloyd *et al.*<sup>2</sup> which employs a combination of bark compression, screening, and water flotation and is expected to handle wood/bark chip mixtures under a variety of conditions.

## SUMMARY

Volume growth of juvenile native aspen is rapid. Increased growth is expected from use of genetically improved trees and through intensive silviculture. Wood and pulp quality for trees 10 years of age and older appears to be adequate for a variety of products. Efficient bark segregation procedures are available. All that appears to be required is a little courage on the part of forest managers.

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<sup>1</sup> Blanchard, F. G. U.S. Patent 3,070,318. 1962.

<sup>2</sup> Lloyd, W. D., Robert E. Lee, and Kimberly-Clark Corporation. Treatment of hardwood chips for bark and wood separation. U.S. Patent 3,337,139. Aug. 22, 1967.

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# YOUTH, MATURITY, AND OLD AGE

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**ABSTRACT.** — Aspen ecology is examined in mature, regenerating, and overmature stands. Investigations in mature stands indicate that aspen growth is controlled primarily by soil water-holding capacity (texture), water table depth, and exposure to wind. These same factors control the rate of aspen conversion but the availability of seed must also be considered. Aspen seedling and sampling densities may be influenced by competing vegetation, site treatment after harvesting, and drainage. Deteriorating (overmature) stands are becoming common, can be regenerated, and should now be considered in forest management planning.

The present aspen forest in northern Wisconsin began with the timber harvesting and extensive fires of the early 1900's, but it was not until the 1950's that aspen was recognized as an important tree species. Then with large areas of aspen forest nearing maturity and providing a supply of pulpwood, aspen suddenly became an economically desirable forest species. Most northern pulpmills now use aspen pulpwood to the near exclusion of other species. In addition, it is recognized as an important food for deer and grouse.

The end of the first aspen forest in Wisconsin is approaching as stands continue to be harvested. In the second aspen forest, which has already begun, there are substantial changes that will have a bearing on the economics and operation of the industries that depend on aspen. The present paper summarizes the author's investigations on the ecology of quaking aspen in north-central Wisconsin as it may affect future aspen silviculture, management and supply.

Because geographic conditions vary greatly and the ecological considerations may be applicable to other States and regions, a brief review of the climatic and soil conditions is necessary. Within the counties of Langlade, Lincoln, Oneida, Vilas, Sawyer and Price, a climatic gradient exists from southeast

(Lincoln County) to northwest (Sawyer County); the average growing season temperature decreases from 68.6° F. to 66.6° F.; the growing season precipitation increases from 14.7 inches to 16.1 inches; and the growing season length decreases from 130 to 107 days (U.S. Department of Agriculture 1941).

Upland soils of the area are classes as Spodosols (weak Podzols intergrading to Gray Brown Podzolics) with an albic ( $A_2$ ) horizon near the surface and an underlying spodic ( $B_{hir}$ ) horizon. Soil textures range from coarse sand to fine silt loam depending on the initial material. Soils formed in glacial outwash (Crivitz, Hiawatha, and Vilas series) range from sand to light sandy loam, and from heavy sandy loam to loam for soils formed in glacial till (Elderon, Iron River, and Pence series). These soils are well to excessively drained but often have water tables in the lower part of the rooting zone. Soils formed in loess have silt loam textures; a mottled fragipan at a depth of 12 to 22 inches usually restricts root growth and slows the rate of percolation through the profile. These soils are moderately well and well-drained on slopes and ridge tops (Goodman, Lynne, and Stambaugh series), and somewhat poorly drained in depressional areas (Clifford series). In this paper, soils formed in glacial outwash, glacial till and loess will be referred to as coarse-, medium-, and fine-textured soils respectively.

## MATURE STANDS

### Growth

Past studies (Kittredge 1938, Stoeckeler 1948, 1960; Wilde and Pronin 1950; Voigt, Heinselman, and Zasada 1957; Meyer 1956; Strothmann 1960; Graham, Harrison, and Westell 1963) have frequently related aspen growth rates to some characteristic of soil (texture, horizon thickness, stoniness, pH, cation exchange capacity and organic matter and nutrient levels) or of site (slope, aspect and topographic position). In the northern Wisconsin study<sup>1</sup> aspen site index was related to some of the above soil and site factors as well as additional factors that proved to be quite important. The following paragraphs on aspen growth summarize the results of that study.

Aspen site index is strongly influenced by soil texture. As the percentage of silt increases from 5 to 90 percent, average site index (age 50) increases from 69 to 85 (fig. 1). A similar relationship exists with decreases in the percentage of sand from 95 to 5 percent. In general, stands on coarse-, medium-, and fine-textured soils have site indices that range from 66 to 72, 72 to 78 and 78 to 85 respectively; however, the influence of other site factors (e.g., water

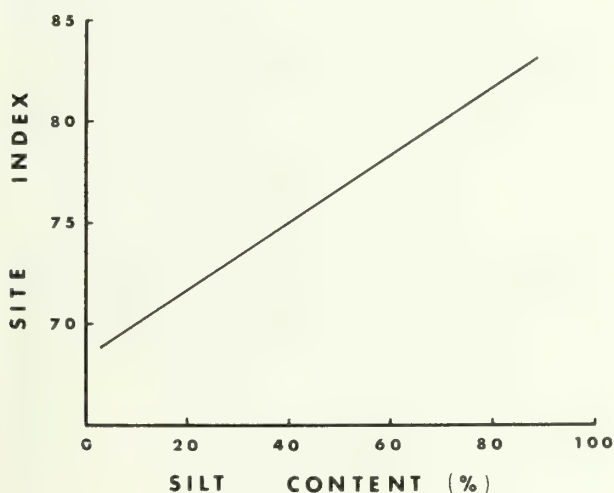


Figure 1. — Relationship of aspen site index to silt content of the soil.

<sup>1</sup> Fralish, James S. 1969. *Site indices and rate of conversion in northern Wisconsin quaking aspen*. Ph.D. dissertation. Univ. of Wisconsin, Madison.

table depth) will cause considerable overlap between ranges. These relationships agree closely with those from other previously cited studies.

Moreover, for growth to occur, a tree must utilize the primary substances obtained from soil — water and nutrients. Thus, using a formula developed by Auclair and Cottam (1971) the available water-holding capacity of the soil was calculated for each stand. The average water storage capacity in inches per foot of soil depth for coarse-, medium-, and fine-textured soils is approximately 1.50, 2.50 and 4.0 respectively. Statistically, the relationship between site index and available water-holding capacity is very strong ( $r = 0.658$ ) and indicates that growth is controlled by available soil water.

Because soil water is of major importance, it is relatively easy to understand how other soil factors affect aspen growth. The stoniness of the soil affects aspen growth by decreasing the water-holding capacity of the soil by decreasing the amount of space where water can be held. A soil that is 25 percent stone will have a site index that is at least five feet lower than for a nonstone soil, other factors being equal.

A water table within the rooting zone will increase aspen growth by providing additional amounts of available water. However, the relationship between site index and water table depth is not linear (fig. 2). Water tables between 3 and 8 feet in depth will greatly increase aspen growth, particularly in the coarse- and medium-textured soils. Water tables deeper than 8 feet will have little effect on growth because few roots penetrate to that soil depth. Water

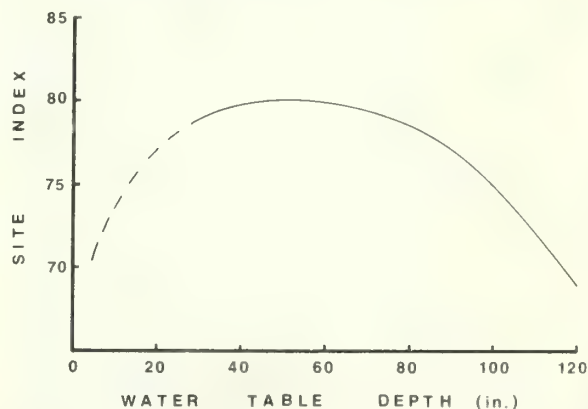


Figure 2. — Relationship of aspen site index to water table depth.

tables less than 2 feet in depth will decrease aspen growth because of decreased space and air that is necessary for roots to develop and support a large tree.

Subsurface horizons of substantially finer texture are particularly important on coarse-textured soils that seldom can retain enough water for maximum aspen growth. These horizons influence aspen growth in a manner similar to that of a water table. They prevent water from being lost from the rooting zone, and, if they are not restrictive to root growth, will substantially increase aspen site index.

The effect of the water table on aspen growth becomes less important on the fine-textured soils (fig. 3), because sufficient water for growth is already held by soil particles. In addition, the shallow fragipan slows the rate of water movement through the profile. However, when water accumulates on or near the surface, as in the poorly drained silt loam soils, site index may be very low (less than 40).

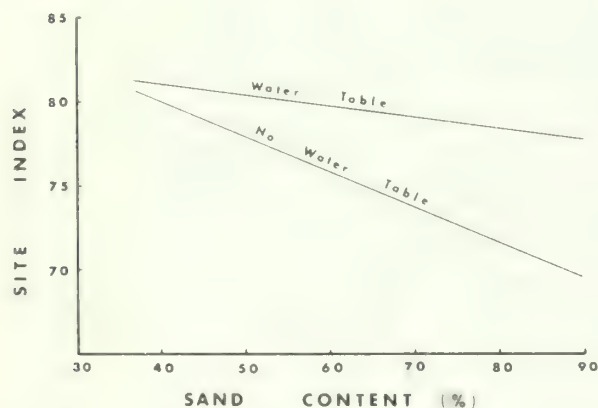


Figure 3. — *Relationship of aspen site index to water table depth and sand content of the soil.*

If aspen growth is primarily dependent on soil water, then will site factors that increase the rate of water loss from a site or tree (evaporation or transpiration) affect growth? The answer is an unqualified yes; because of more rapid soil water depletion, there will be more frequent periods of longer duration when water is unavailable to the tree. Most of the previous site studies on aspen have investigated aspect, slope, and topographic position. Stands located on south, southwest, and west aspects, on steep slopes, or on ridge tops tend to have lower site indices because of increased evapotranspiration or runoff rates.

Wind is an additional factor that has been usually overlooked in most aspen studies but it is important because wind also affects evapotranspiration rates. Exposure to wind is nearly as important in influencing aspen growth as soil water-holding capacity and water table depth. Isolated stands and stands located on ridge tops have lower site indices because of higher internal wind velocities than stands on middle slopes, or stands protected by forest on two or more sides, particularly the south, southwest, and west sides. In general, protected stands whether in valleys, between ridges, or surrounded by forest, have higher site indices than unprotected stands, other factors being equal.

Soil nutrient levels have very little effect on aspen growth in northern Wisconsin; similar results for Wisconsin aspen were obtained by Stoeckeler (1960). However, Voigt and others (1957) and Stoeckeler (1960) found that site indices increased as levels of phosphorus, potassium, calcium, and magnesium increased in Minnesota soils.

## Compositional Changes

Shade intolerant species such as aspen eventually will be replaced by shade tolerant species that form a more stable forest community. In the northern Wisconsin study,<sup>2</sup> the environmental factors that control growth, soil water-holding capacity, water table depth, and exposure, also were found to control the species composition of stands replacing the present aspen stands. However, the presence or absence of a seed source may also have a significant effect. The following paragraphs on compositional changes in aspen stands summarize the results of the above study.

On coarse-textured soils (Crivitz, Hiawatha, and Vilas series), rapid aspen succession is not a problem. At present, 70 percent of the aspen stands do not have any or have very light understories. Hardwood species such as sugar maple, white ash, basswood, and American elm rarely grow on these soils because of their droughty nature. In 30 percent of the study stands there are up to 150 stems per acre of red maple, white birch, and red oak.

If mature white pine trees are present within a 10-chain radius of a stand generally there will be

<sup>2</sup> *Ibid.*

white pine in the understory. However, even with an adjacent white pine seed source, the present white pine understories are not dense, having an average of only 135 stems per acre.

After aspen stands are clearcut on coarse-textured soils at the end of the present rotation, aspen suckers sufficient to form another stand will grow through the low density pine and/or hardwood understory which averages less than 200 stems per acre for all stands investigated. A few mixed stands of aspen-hardwood or aspen-hardwood-pine may result but the problem of aspen conversion may be more serious in one or two rotations when the understories are better developed.

On medium-textured sandy loam and loam soils (Elderon, Iron River, and Pence series), white pine and northern hardwood species also may be found in mixture or separately in the understory. The proportion of pine and hardwood in the understory usually depends on the availability of seed from adjacent seed sources. In general, aspen stands on the medium-textured soils exhibit moderate conversion rates. Therefore, changes in the acreage and volume of aspen on these soils can be expected.

After a clearcut of stands on the medium-textured soils, approximately 25 percent of the sites will immediately convert to the northern hardwood or northern hardwood-white pine forest type, and another 45 percent of the new stands will be some combination of aspen, northern hardwood, and pine. Approximately 30 percent of the stands will regenerate to relatively pure stands of aspen.

Stands on the moderately well-drained and well-drained fine-textured silt loam soils (Goodman, Lynne, and Stambaugh series), are rapidly converting to the northern hardwood forest type. These soils have high water holding capacities and are rapidly invaded by sugar maple, red maple, yellow birch, white ash, green ash, American elm and red elm. White pine is usually not a component of the forest understory in many parts of north-central Wisconsin. White pine of any size is noticeably absent, particularly in the Newwood River area of Lincoln County and parts of Price and Sawyer Counties. Surveyor's records indicate that white pine was once a component of the forest in these areas, but apparently it was eliminated during the cutting and fires of the early 1900's.

After aspen stands are clearcut on the silt loam soils, 45 percent of the sites will immediately convert to the northern hardwood forest type and another 45 percent will convert to some combination of aspen and hardwood. Approximately 10 percent of the sites will remain in pure aspen. At the end of the next rotation, aspen will not be an important species on the fine-textured soils unless drastic methods are used to maintain it.

## YOUTH

Foresters recently entered a new phase in aspen management when the vast areas of mature stands began to be replaced by young stands of aspen or northern hardwoods. Management problems and procedures for these young aspen stands are considerably different than those for mature stands and several questions need to be answered.

How does reproduction density vary with the soil texture, amount of overstory remaining, or understory density? How effective is site treatment in removing competing species and maintaining aspen? Do the results of site treatment vary with the soil texture and drainage?

In north-central Wisconsin, clearcut aspen stands on coarse-textured loamy sand and fine-textured silt loam soils were studied in an attempt to answer these questions (Fralish and Loucks 1968; Fralish 1971). Approximately one-half of the clearcut stands investigated had been subsequently treated (cleared) by a bulldozer and a K-G blade or disk. Generally the data for clearcut but untreated stands on silt loam soil are for stands that are slowly changing in composition; rapidly converting stands were more difficult to locate since, after cutting, these stands immediately converted to northern hardwood species.

In general, a few small trees remained after harvesting operations in clearcut stands; on a per acre basis only 51 and 44 trees ( $\geq 3.5$  inches) remained standing on loamy sand and silt loam soils respectively (table 1). Aspen reproduction did not appear to be affected by this low number of overstory trees, although larger numbers could increase competition and reduce the number and growth of suckers. Stands that were both clearcut and treated by bulldozing had no overstory trees and the brush and hardwood understory common to fine-textured soil was also absent.

Table 1. — *Density of residual trees in 3- and 4-year-old stands after clearcutting and in overmature stands on loamy sand and silt loam soils (stems/acre  $\geq$  3.5 in. d.b.h.)*

Species	3- and 4-year-old stands :		Overmature stands	
	Loamy sand	Silt loam	Loamy sand	Silt loam
Aspen	15	38	115	138
Pine	8	0	3	1
Northern hardwoods	2	6	1	93
Red maple	10	0	7	1
White birch	14	0	7	11
Miscellaneous	2	0	2	10
Total	51	44	135	254

The average number of aspen seedling and sapling stems per acre for 3- and 4-year-old clearcut stands on loamy sand soils (Crivitz, Hiawatha, Vilas series) range between 12,700 and 13,700 on both treated and untreated sites (table 2). In 1-year-old stands, there are probably 16,000 to 18,000 stems per acre. The data indicate that lack of aspen reproduction is not a problem on sandy soils even where the former stand was mixed aspen and jack pine. In stands investigated disking had been employed to stimulate jack pine reproduction rather than aspen; at present aspen dominates these sites.

After stands were harvested on moderately well and well-drained silt loam soils (Goodman, Lynne, and Stambaugh series), aspen reproduction developed quickly and in high numbers (approximately 18,000

stems per acre in 1-year-old stands )if hazel and northern hardwoods were absent from the site. Very few of these stems were browsed by deer. In 3- and 4-year-old stands, aspen density decreased to 12,352 stems per acre (table 2) indicating a high mortality rate due to intense interspecific competition.

However, aspen suckers developed rather slowly and in lower numbers (approximately 5,600 stems per acre in 1-year-old stands) on fine-textured soil if heavy hazel was present on the site. Approximately 50 to 60 percent of these stems were browsed by deer. Moreover, suckers apparently continued to develop; at age 4 there were 8,162 stems per acre. Hazel definitely reduces aspen suckering but does not compete sufficiently to prevent a new stand from developing. Where hazel is very dense, prescribed burning can probably be used to reduce competition.

Table 2. — *Density of seedlings and saplings in 3- and 4-year-old stands after clearcutting and in overmature stands on loamy sand and silt loam soils (stems/acre  $<$  3.5 in. d.b.h.)*

Species	3- and 4-year-old stands						Overmature stands	
	Clearcut			Clearcut and treated				
	Sand	Silt <sup>1/</sup>	Silt <sup>2/</sup>	Sand	Silt <sup>3/</sup>	Silt <sup>4/</sup>	Sand	Silt
Aspen	13,647	12,352	8,162	12,766	10,764	8,084	1,602	728
Pine	5/358	0	0	6/233**	0	0	5/116*	0
N. hardwoods	0	48	24	0	80	20	2	1,537
Red maple	80	812	266	542	40	20	245	309
Red oak	132	0	0	60	0	0	206	2
Willow	220	1,820	602	873	880	5,408	129	297
Miscellaneous	362	912	196	461	1,992	128	534	174
Total	14,799	15,944	9,250	14,935	13,752	13,660	2,834	2,045

<sup>1/</sup> No understory competition.

<sup>2/</sup> Heavy brush competition.

<sup>3/</sup> Moderately well-drained soils.

<sup>4/</sup> Somewhat poorly drained soils.

<sup>5/</sup> White pine.

<sup>6/</sup> Jack pine.

Dense advanced hardwood reproduction prevents aspen suckering. As previously mentioned, the clear-cut but untreated stands on silt loam soils generally had low numbers of advanced hardwood reproduction and, therefore, had high numbers of aspen suckers. On sites where large numbers (500 or more per acre) of hardwood stems are present, the conversion rate is rapid and the site must be treated if aspen is to be maintained. The treated sites are now covered with well-stocked young aspen stands (table 2) but without treatment aspen would have been excluded as the sites were stocked with advanced hardwood reproduction after clearcutting but prior to treatment.

On somewhat poorly drained silt loam soils (Clifford series), the treated sites had approximately 18,000 stems per acre at age one, but at age four only 8,084 stems remained and most of these stems were located on small raised mounds. The surrounding lower and more poorly drained areas were nearly devoid of aspen reproduction. Therefore, it appears that sites with somewhat restricted drainage should not be treated but be allowed to convert to northern hardwoods.

Other species such as black cherry, red maple, white birch, junberry, and pin cherry are found in nearly all stands. Only willow showed a relationship between density and soil texture or site treatment (table 2). Willow has a much higher density on the silt loam soil, especially on the treated sites. These higher densities reflect not only the more favorable moisture conditions but also the stimulating effect of site disturbance.

## OLD AGE

The phenomenon of aspen stand deterioration (natural breakup) is a relatively new problem in forest management (Fralish and Loucks 1968; Fralish 1971). It should not be assumed to occur with the same frequency or at the same stand age throughout the geographic range of aspen. Some evidence indicates that natural breakup varies with climatic conditions.

In central Wisconsin maximum stand age ranges from 25 to 35 years (Portage County), while 75 miles to the north (Lincoln County) maximum stand age ranges from 45 to 50 years. In Sawyer County, 100 miles northwest of Lincoln County, maximum stand ages range from 55 to 60 years. Aspen stand ages in northern Minnesota may reach 100 years (Zehngraff

1947). Although other climatic factors may be influencing maximum stand age, there is some correspondence to summer temperatures. Mean July temperatures for these four geographic areas are 71° F., 69° F., 67° F., and 63° F. respectively (U.S. Department of Agriculture 1941).

Deterioration appears to follow a definite pattern in each stand. During the ages of rapid growth the even-aged condition of the stands creates severe competition for light and moisture. As less vigorous, slower growing individuals die, openings are created that are rapidly closed through radial crown growth of faster growing individuals. Because of the closely packed canopy and even-aged condition, the trees become dependent on a continuous canopy to prevent exposure and breakage by wind.

Growth slows as maturity is reached, thus when individual trees die, the canopy holes cannot be closed as during earlier periods of rapid growth. As the canopy becomes more open, the frequency of breakage increases. Moreover, the open canopy exposes the stand to the stresses of increased wind, sunlight, and evaporation. Aspen physiology is not designed to tolerate these sudden stresses and the tree usually dies, or becomes less vigorous and thus more susceptible to disease and insect attack which further increases the frequency of breakage. The entire process of deterioration may take no longer than three or four years.

In mature stands, aspen density may average from 300 to 400 trees per acre. In deteriorating stands, aspen density ranges from 115 to 138 trees per acre (table 1) and is decreasing. The stands are relatively open and the trees often, but not always, show evidence of heartrot.

Overmature stands on loamy sand soil have low numbers of aspen seedlings and saplings because suckering is inhibited by the remaining overstory (table 2). The stem densities of other species are also low so that these sites are converting to open, non-productive forest and brush, primarily uneven-aged aspen, *Rubus*, and related species. However, as long as a few live aspen trees per acre remain, such stands can probably be regenerated through the removal of the overstory and diskings to stimulate suckering. In some cases, it may be preferable to refrain from treating such areas in order to create a natural opening for wildlife.

Where aspen stands deteriorate on fine textured soils, generally hardwoods will occupy the site because an overstory remains to inhibit aspen suckering and there is severe competition from the hardwood understory. Site treatment to remove the overstory and hardwood understory will probably regenerate the aspen; however, more research needs to be done on deteriorating stands.

## MANAGEMENT IMPLICATIONS

The ecological relationships between quaking aspen, soil and site characteristics, and associated vegetation have both long and short management implications to land managers. The relationship between site index and conversion rate, both of which increase on the fine-textured silt loam soils, is important. The best aspen sites are being lost to the northern hardwood types, thus as conversion continues the total volume and acreage of aspen will decline drastically. Average aspen growth and volume per acre can be expected to decrease because only the poorer sites will remain in aspen.

Perhaps management should consider the economics of using more hardwood pulp as opposed to the continued use of aspen pulp. Hardwood species are slower growing, but no effort is needed to maintain them on silt loam soil. Maintenance of aspen through site treatment methods results in increased costs, but aspen is faster growing and at present mills are equipped to handle aspen pulp. Because the greatest conversion to hardwood will occur at the end of the present rotation, these economic evaluations should be made immediately.

However, site treatment to regenerate aspen must be judiciously applied. Poor aspen sites that are converting to northern hardwoods on somewhat poorly drained fine-textured soil should be permitted to continue. On coarse-textured soils, site treatment should not even be considered. In areas where overmature stands are common, regenerating these stands may be necessary especially with the reduction in aspen acreages in the years ahead. In general, it appears that foresters will have to do some precise management planning.

Finally, foresters should not limit the types of site treatment methods that can be employed to regenerate aspen. At present, only mechanical methods have

been attempted and found satisfactory. However, the present aspen forests were the result of cutting and fire, thus prescribed burning should be investigated as a possible management tool.

## ACKNOWLEDGMENTS

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## CESSION

## AL MINNESOTA

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in Minnesota will not be harvested,  
pend on natural successional processes.  
ire wood supplies and deer and grouse  
rest succession in north-central Minne-  
sition that will occur under different  
on are described leading to stands of  
hrub understories, and "shrubwood."

states. In addition, the great value of this type for  
leer, moose, and grouse habitat make a knowledge  
of the successional processes of even greater concern.

This report considers the successional processes and  
ite interrelationships of aspen stands in Minnesota  
under relatively undisturbed conditions. It considers  
projections in time assuming the stands studied will  
not be logged or burned but subject to "normal"  
attrition by insects, disease, old age, and wind.

### THE STUDY AREA

The study was conducted in Itasca State Park in  
north-central Minnesota. This area was selected be-  
cause it has been subject to a minimum of disturb-  
ance by logging or fire for the life span of the existing  
aspen stands. Itasca State Park covers approximately  
33,000 acres and contains elements of the mixed con-  
ifer-hardwood, deciduous, and boreal forests with  
nfluence of prairie conditions to the west. The cli-  
mate is typically continental. Surficial geology reflects  
a complicated glacial history and the effects of the  
movements of three ice lobes. Soils have developed on  
tills and outwash of gray drift origins. They belong  
mainly to the Nebish-Rockwood and Menahga-Mar-  
quette soil associations and vary widely in soil texture.

### SAMPLING AND METHODS

An attempt was made to sample the entire range  
of ecological conditions prevailing in the area. From  
a preliminary survey representing all major upland

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pose regeneration problems unless conversion to other  
species is desired. However, what succeeds the aspen  
on the large uncut areas is of great importance to  
the wood-based industry of Minnesota and the Lake

<sup>1</sup> Lundgren, Allen L. *Timber management: pro-  
jections for the 70's. (Unpublished paper for A  
Symposium on the White-tailed Deer. 1971.)*

<sup>2</sup> See Leuschner, William A. *Projections of inven-  
tories in the Lake States. p. 10-15.*

Where aspen stands deteriorate on fine textured soils, generally hardwoods will occupy the site because an overstory remains to inhibit aspen suckering and there is severe competition from the hardwood understory. Site treatment to remove the overstory and hardwood understory will probably regenerate the aspen; however, more research needs to be done on deteriorating stands.

## MANAGEMENT IMPLICATIONS

The ecological relationships between quaking aspen, soil and site characteristics, and associated vegetation have both long and short management implications to land managers. The relationship between site index and conversion rate, both of which increase on the fine-textured silt loam soils, is important. The best aspen sites are being lost to the northern hardwood types, thus as conversion continues the total volume and acreage of aspen will decline drastically. Average aspen growth and volume per acre can be expected to decrease because only the poorer sites will remain in aspen.

Perhaps management should consider the economics of using more hardwood pulp as opposed to the continued use of aspen pulp. Hardwood species are slower growing, but no effort is needed to maintain them on silt loam soil. Maintenance of aspen through site treatment methods results in increased costs, but aspen is faster growing and at present mills are equipped to handle aspen pulp. Because the greatest conversion to hardwood will occur at the end of the present rotation, these economic evaluations should be made immediately.

However, site treatment to regenerate aspen must be judiciously applied. Poor aspen sites that are converting to northern hardwoods on somewhat poorly drained fine-textured soil should be permitted to continue. On coarse-textured soils, site treatment should not even be considered. In areas where overmature stands are common, regenerating these stands may be necessary especially with the reduction in aspen acreages in the years ahead. In general, it appears that foresters will have to do some precise management planning.

Finally, foresters should not limit the types of site treatment methods that can be employed to regenerate aspen. At present, only mechanical methods have

been attempted and found satisfactory. However, the present aspen forests were the result of cutting and fire, thus prescribed burning should be investigated as a possible management tool.

## ACKNOWLEDGMENTS

The author wishes to acknowledge the financial support of the North Central Forest Experiment Station, St. Paul, Minnesota, and the Wisconsin Department of Natural Resources, Madison, Wisconsin, and the technical assistance of Dr. Orie Loucks, Department of Environmental Studies, University of Wisconsin, Madison, Wisconsin.

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# NATURAL SUCCESSION IN NORTH-CENTRAL MINNESOTA

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**ABSTRACT.**—A large area of aspen forest in Minnesota will not be harvested, and the nature of the succeeding forest will depend on natural successional processes. These changes have great significance for future wood supplies and deer and grouse habitat. This study examines the nature of forest succession in north-central Minnesota and describes variations in stand composition that will occur under different site conditions. Three broad lines of succession are described leading to stands of tolerant hardwoods, mixed oak with dense shrub understories, and “shrubwood.”

## THE PROBLEM

The aspen type covers 13½ million acres, approximately a quarter of the commercial forest land in the Lake States. In Minnesota it is the State's largest forest type, occupying over 5 million acres. Most of this type is in the older age classes, between 30 and 60 years. Using timber management projections by Lundgren<sup>1</sup> it appears that the present two million cord annual cut of this species will increase by an area equivalent to about 5 thousand acres per year. However, even with this increasingly large acreage cut there is a considerable present underutilization of the aspen type, and a vast area in excess of two million acres will not be harvested and will be subject to “natural” successional processes. This is particularly true in Minnesota where the ratio of utilization to acreage and growth is lower.<sup>2</sup>

The great capacity of aspen to sucker from shallow lateral roots following logging or fire is well known. Harvested stands, particularly if clearcut, seldom pose regeneration problems unless conversion to other species is desired. However, what succeeds the aspen on the large uncut areas is of great importance to the wood-based industry of Minnesota and the Lake

States. In addition, the great value of this type for deer, moose, and grouse habitat make a knowledge of the successional processes of even greater concern.

This report considers the successional processes and site interrelationships of aspen stands in Minnesota under relatively undisturbed conditions. It considers projections in time assuming the stands studied will not be logged or burned but subject to “normal” attrition by insects, disease, old age, and wind.

## THE STUDY AREA

The study was conducted in Itasca State Park in north-central Minnesota. This area was selected because it has been subject to a minimum of disturbance by logging or fire for the life span of the existing aspen stands. Itasca State Park covers approximately 33,000 acres and contains elements of the mixed conifer-hardwood, deciduous, and boreal forests with influence of prairie conditions to the west. The climate is typically continental. Surficial geology reflects a complicated glacial history and the effects of the movements of three ice lobes. Soils have developed on tills and outwash of gray drift origins. They belong mainly to the Nebish-Rockwood and Menahga-Marquette soil associations and vary widely in soil texture.

## SAMPLING AND METHODS

An attempt was made to sample the entire range of ecological conditions prevailing in the area. From a preliminary survey representing all major upland

<sup>1</sup> Lundgren, Allen L. *Timber management: projections for the 70's*. (Unpublished paper for A Symposium on the White-tailed Deer. 1971.)

<sup>2</sup> See Leuschner, William A. *Projections of inventories in the Lake States*. p. 10-15.

cover types, 36 stands were selected as representative of the upland site spectrum (Kurmish).<sup>3</sup> Intensive plant and soils data were collected on these stands. In addition, 25 aspen stands were added to intensify the sampling of this cover type; another 27 stands included lowland types not in the original survey. This total of 88 stands represented all major forest cover types and included 35 aspen stands. The basic data collected included tree diameters, ages, and heights, shrub understory characteristics, soil profile descriptions, and plant lists of woody and herbaceous species.

Prediction of current successional trends in forest stands require a knowledge of the species composition of the present stands, the role played by each species, and the site characteristics. Data on species composition were obtained from the field studies for individual stands. Since aspen is a transient type on a great range of site conditions, succession to other types can be expected to vary depending on site.

To provide the necessary framework of site or ecological characteristics, the method of synecological coordinates was used. This method was formalized by Bakuzis<sup>4</sup> and is described by Bakuzis and Hansen (1959). Briefly, it is based on a knowledge of the behavior of individual plant species in nature under conditions of competition with respect to moisture, nutrient, heat, and light factor complexes. Individual species are given relative values from 1 to 5 according to their prevailing occurrence at different intensities of the factor complexes. Species occurring at the lowest intensity of the factor complex are assigned a value of 1 for that factor and those associated with the highest intensity are rated 5. A species such as jack pine with high light requirements has a value of 5 for light. Tamarack, confined in natural stands to the wettest sites, has a value of 5 for moisture. Community values are computed as averages of the values of all species in the community. These values were determined for all stands studied. The edaphic

complex as described by the moisture-nutrient values was considered to provide the basic framework for examining the successional patterns of the aspen stands.

Each stand was classified by its cover type using preponderance of basal area by species as the basis. Ten cover types were recognized (upper diagram, fig. 1). The stands were analyzed as to their community values. Each stand was then plotted by its pair of moisture and nutrient values to produce the total distribution pattern (fig. 1). Eight site units representing combinations of different moisture and nutrient levels were identified as being ecologically meaningful.

## LITERATURE REVIEW

While numerous studies of forest succession have been made in Itasca State Park and elsewhere in Minnesota, two are considered particularly relevant to this report. Heinselman (1954) investigated natural conversion in the aspen-birch type in the Lake States using the character of the "invading cover type" as indicative of the developing forest types. He defined 5 "ecological regions" in the aspen-birch type distribution in the Lake States. The Itasca State Park area was located in an oak-pine-hardwood belt. Heinselman predicted that about a fourth of the total Lake States aspen area would convert primarily to northern hardwoods and balsam fir in 30 to 50 years. In over half the aspen area there was no appreciable present indication of conversion. He estimated complete conversion to be in process on over 40 percent of the type in Wisconsin and Upper Michigan but on only 20 percent in Minnesota.

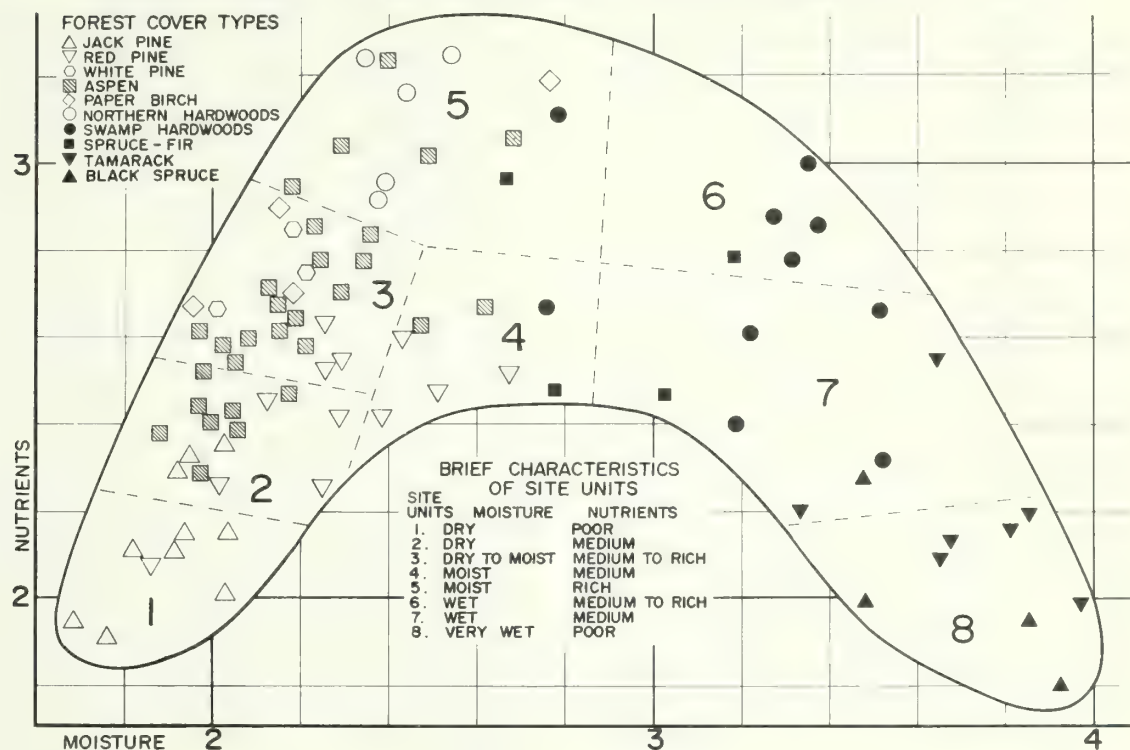
Ness<sup>5</sup> described the aspen type in Itasca State Park in connection with his research on the comparative dynamics of upland forest communities. While aspen currently covers almost half the total park acreage, Ness predicts the structural disintegration and overmaturity of most of the aspen cover type in 30 to 40 years. In few instances does aspen appear capable of predominance in the next generation stand overstory.

<sup>3</sup> Kurmis, V. *Dynamics of advance reproduction in upland forest communities in Itasca State Park, Minnesota. (Unpublished Ph.D. thesis, University of Minnesota, 166 p. 1969.)*

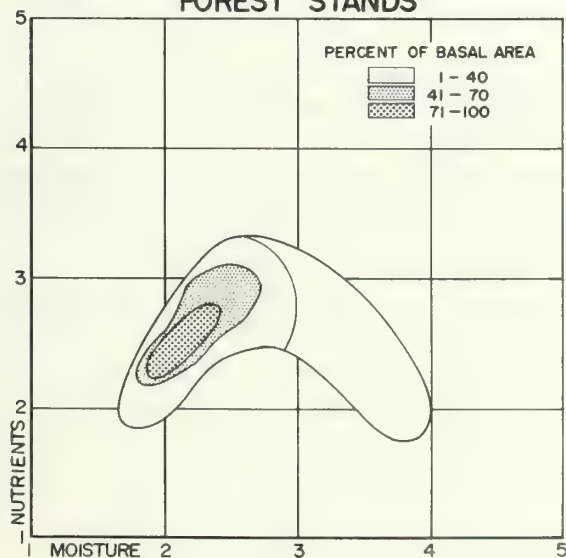
<sup>4</sup> Bakuzis, E. V. *Synecological coordinates in forest classification and in regeneration studies. (Unpublished Ph.D. thesis, University of Minnesota, 242 p. 1959.)*

<sup>5</sup> Ness, D. D. *Comparative dynamics of upland forest communities in Itasca State Park, Minnesota. (Unpublished Ph.D. thesis, University of Minnesota, 447 p. 1971.)*

# ASPEN - SITE RELATIONS IN MINNESOTA FOREST COVER TYPES AND SITE UNITS IN ITASCA STATE PARK



## ASPEN DOMINANCE IN ITASCA PARK FOREST STANDS



## ASPEN PRESENCE IN MINNESOTA FOREST STANDS

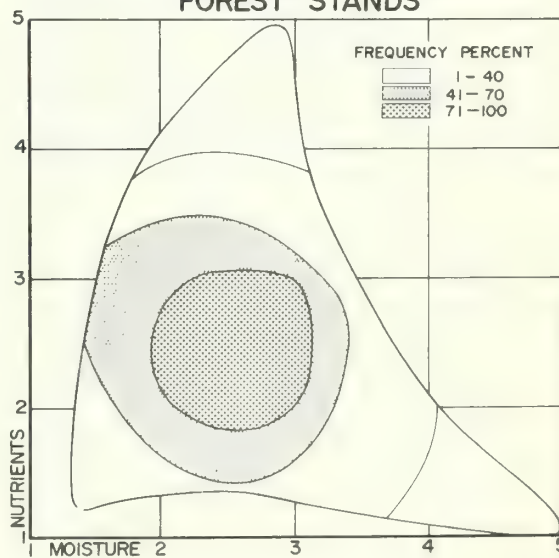


Figure 1. — *Aspen distribution and site relationships in moisture-nutrient coordinates.*

Ness postulates a disintegration within 30 to 40 years of most of the existing aspen overstory and the concomitant development of a vigorous shrub under-story and invasion by more shade tolerant hardwoods. For eight of 10 aspen stands studied succession to either transitional northern hardwoods or a "shrub-wood" within 50 years was projected.

## THE DATA

The pattern of relationships between cover types and site units for all 88 stands was indicated by positioning the various cover types in the edaphic (moisture-nutrient) field (upper diagram, fig. 1). For example, all jack pine stands fall in site units 1 (dry, nutrient-poor) or 2 (dry, medium nutrient).

The distribution of aspen within the total forest site complex in Itasca State Park is shown in the lower left diagram in figure 1. Aspen dominance in each stands is indicated by its percent composition of the total stand basal area. In general, aspen tends to dominate on dry to moist, medium-nutrient sites. It has little dominance on the dry, nutrient-poor sites, and is almost absent from the richest sites. It is totally absent at any nutrient level on wet or very wet sites.

Presence of aspen on the entire range of forest sites in Minnesota is plotted in the lower right diagram in figure 1. This refers to the percent of all stands in any portion of the edaphic field which contain aspen. Again, aspen occurs most frequently on dry to moist sites of medium nutrient levels. It is absent or rare on the driest, richest, and wettest sites.

The basal area distribution and intensity of occurrence of each tree species was studied (fig. 2). Each tree species was grouped into three size categories: tree (over 4 inches d.b.h.), sapling (1.0 to 3.9 inches d.b.h.), and seedling (under 1.0 inch d.b.h.). These patterns help clarify the competition characteristics of some of the species. For example, red maple trees are shown to be confined to the moister and richer sites although smaller saplings and seedlings are found on drier and poorer sites. Ironwood occurring on similar sites is shown to be an understory species with little tree-sized representation.

Patterns of shrub species' occurrence and abundance under aspen stand overstories can be seen in figure 3.

## OBSERVATIONS AND CONCLUSIONS

### Distribution Patterns of Characteristic Species

All sizes (tree, sapling, seedling), of quaking aspen were found to occur over the same range of sites except that no saplings were found in aspen communities on nutrient-rich sites (fig. 2). These sites are characterized by early and severe competition from tolerant species. This means no reproduction survival and the early elimination of suppressed trees. In the sapling class (less than 4 inches at d.b.h.) there are some old, suppressed trees that have never attained tree size. This may also be true with some other intolerant species such as bigtooth aspen and paper birch. Thus, the significance of the presence of saplings of these species may be overrated in terms of community succession.

Northern red oak is a common aspen stand component. It has a wide distribution, especially in the seedling stage, from dry, nutrient-poor to moist, nutrient-rich sites. However, reproduction is less frequent on dry, nutrient-poor sites. Red oak reproduction competes well on dry to moist, medium-nutrient sites with high shrub densities. Saplings are lacking on rich sites. The distribution of bur oak is narrower than that of red oak. Bur oak trees, saplings, and seedlings are largely lacking in aspen stands on dry, nutrient-poor and moist, nutrient-rich sites.

Red maple is considered a subclimax species, and it functions as an intermediate in many forest stands. It is most commonly found in the understory. The occurrence of red maple in tree sizes is sporadic in aspen stands. Saplings are widespread. Reproduction is most abundant in aspen stands on better sites and sometimes exceeds 10,000 seedlings per acre. Red maple is able to compete successfully with shrub and ground cover species. Its growth rate under conditions of strong shrub competition is similar to that of red oak. Sugar maple is commonly a constituent of old aspen stands on better sites. Trees, saplings, and seedlings are well represented. Sugar maple reproduction is able to withstand complete suppression for several years and still respond strongly to release.

White pine is present in some aspen stands as old, scattered veterans. Seedlings may be quite numerous on better sites; however, inadequate light, deer browse, and blister rust account for the lack of saplings in aspen stands.

# TREES, SAPLINGS AND SEEDLINGS OF ASPEN STANDS IN ITASCA STATE PARK AREA

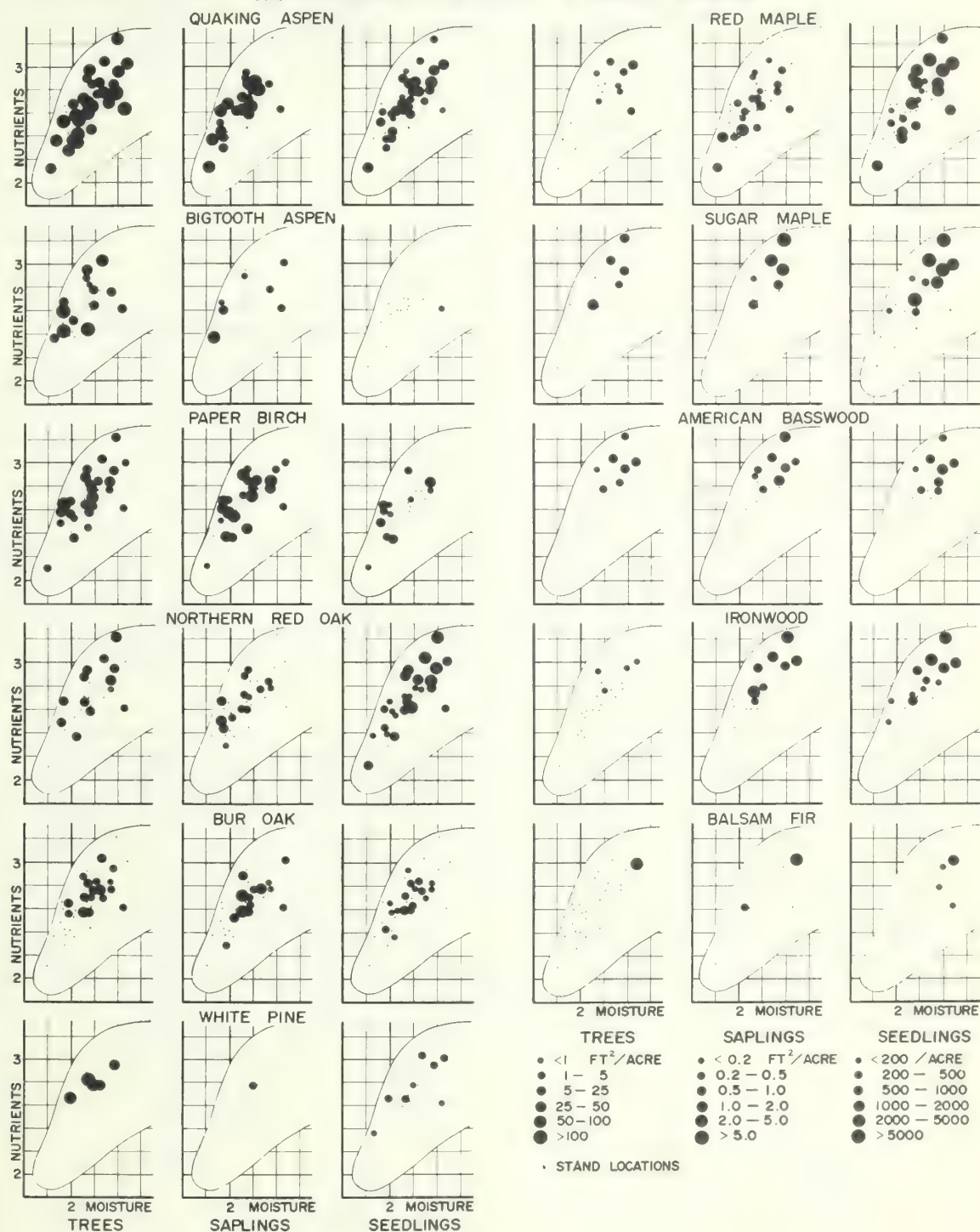


Figure 2. — Distribution of aspen and its associated species as measured by basal area of trees, saplings, and numbers of stems of seedlings in moisture-nutrient coordinates.

# SHRUBS OF ASPEN STANDS IN ITASCA STATE PARK AREA

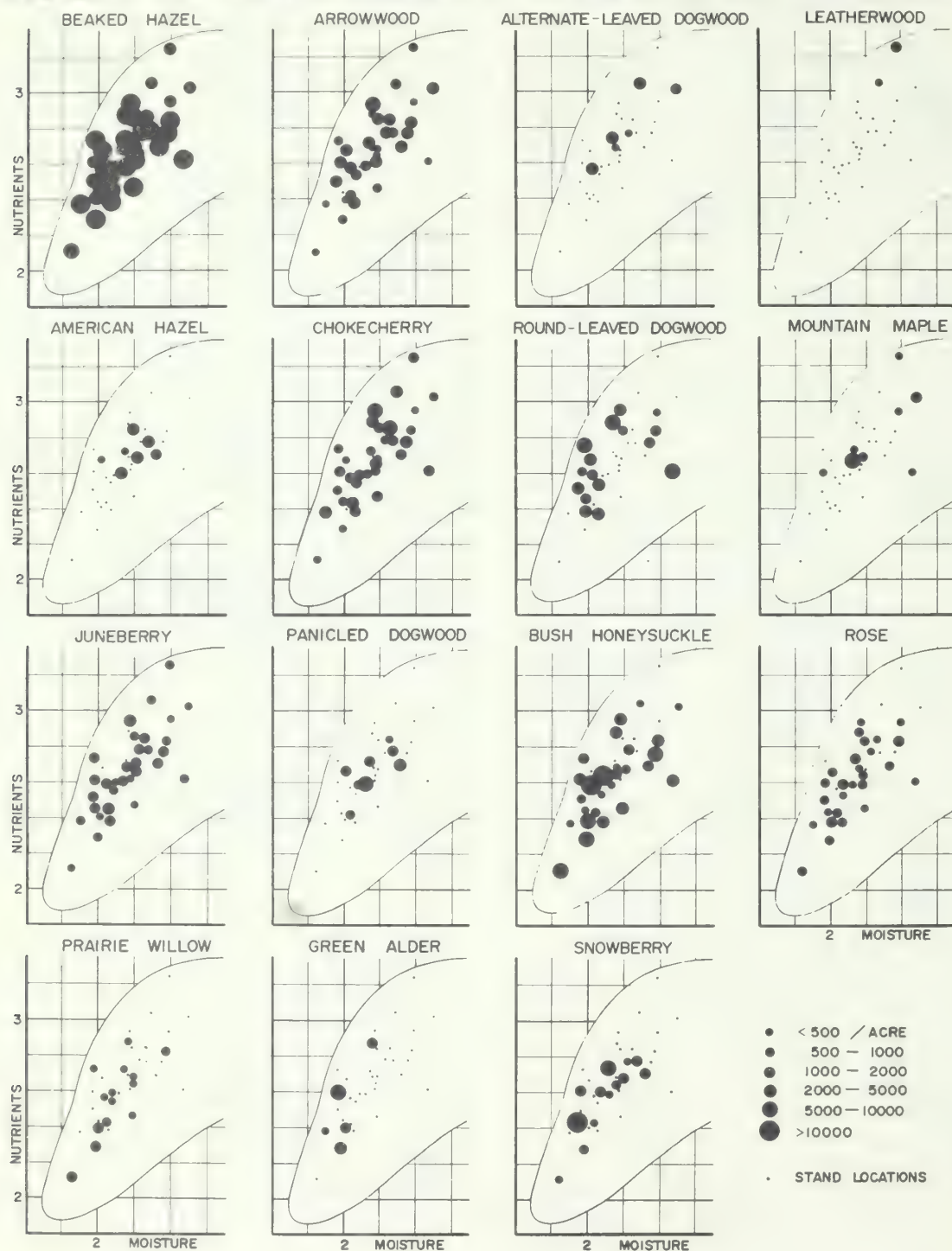


Figure 3.—Shrub distribution in aspen stands in moisture-nutrient coordinates.

Being a boreal species, balsam fir is on the southwestern edge of its natural range. In the Itasca State Park area it tends to occupy moist and cool sites. It is largely lacking in aspen stands. Reproduction is only found on moist, medium-nutrient sites in places adjacent to wet areas (fig. 2).

Shrubs are generally distributed over the total range of aspen stands. The greatest abundance and diversity of shrubs occur on dry to moist, medium-nutrient sites with beaked hazel predominating (fig. 3).

### **Successional Trends**

Succession in forest stands will be toward the most tolerant species capable of invading, establishing, and regenerating under the site conditions present. Aspen is an intolerant species of well-known transient character in the absence of disturbance, and most of its associates except jack pine, paper birch, and bigtooth aspen have greater shade tolerance. What succeeds a present aspen stand will depend on the relative tolerance of any associated species, and their affinity for the various site characteristics. These relationships for forest stands in the Itasca State Park area are shown in upper figure 1 and figure 2.

### **Succession in Pure Aspen Stands**

Where no other species are associated with the aspen, succession under natural conditions will depend on the nature of the final breakdown process. If the stand is subject to drastic blowdown, it is possible for a considerable number of suckers to regenerate a second stand of aspen. However, in most instances a more gradual deterioration will result in a limited stand of aspen with a greatly increased brush component, the "shrubwood" described by Ness.<sup>5</sup> This will happen because several brush species, especially beaked hazel in this area (fig. 3), are aggressively present over the total range of site occupied by aspen stands.

### **Succession of Aspen with Intolerant Associates**

When aspen is mixed with paper birch, red pine or jack pine, species of essentially equal intolerance, the nature of the second stand will depend on the

relative longevity of the species involved. The pines and paper birch have normal lifespans exceeding that of aspen and can be expected to outlive it. However, since these species like aspen are transient in the absence of disturbance, they will in turn be replaced by a shrubwood type, characterized by a distinct shrub canopy with occasional trees in various states of maturity.

### **Succession of Aspen with Xeric Hardwood Associates**

The two oaks, northern red and bur, occur in many aspen stands to the extent of 25 to 50 or more square feet of basal area plus a considerable number of saplings and seedlings (fig. 2). These species have greater longevity and tolerance than the aspen and will form the second stand, the stocking depending on their current abundance and age structure. Such stands can be expected to continue to have a dense shrub understory.

### **Succession of Aspen with Tolerant Hardwood Associates**

The tolerant hardwoods in this area include sugar maple, basswood (*Tilia americana*), ironwood, and red maple. These species, except for red maple, are largely confined to site unit 5 (moist, rich) (figs. 1 and 2). In aspen stands on those site conditions succession is inevitably to these climax species. The degree of stocking of the regenerated hardwood stand will vary, but the ability of these species to regenerate under their own cover will promote more complete stocking in time. The shrub layer in these stands will be sparse or absent and consist of scattered leatherwood, alternate-leaved dogwood, and occasional other species (fig. 3).

### **Succession of Aspen with Spruce and Balsam Fir Associates**

It should be noted that white spruce and balsam fir are only infrequent associates in the aspen type in this area. Balsam fir is at the southwestern fringe of its range and it does not appear capable of assuming the role of a dominant climax species as it does

in the boreal region. It reproduces with some abundance under aspen overstories on moist sites (fig. 2). However, in only one aspen stand was it found to reach the overstory position. Permanent plots in this area indicate that as the overstory breaks up, balsam fir tends to disappear in favor of brush or hardwoods except on wet microsites.

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# SILVICS AND ECOLOGY IN CANADA

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**ABSTRACT.**—Aspens are widely distributed and grow under a wide range of ecological conditions in Canada. The most productive aspen stands in Canada are located north of the height of land where rivers flow toward Hudson Bay. Formation of clones, due to repeated vegetative propagation, is silviculturally the most significant feature of aspen stands. Clones vary in their suckering ability, phenology, growth vigour, form, and disease susceptibility. High grading of superior clones is detrimental to the future of aspen resource; clearcutting is recommended to ensure adequate regeneration and to conserve a broad genetic pool.

Poplars in Canada constitute 54 percent of all merchantable hardwoods, or about 9 percent of the total net merchantable forest resource. Of the eight poplar species native to Canada, trembling aspen and largetooth aspen are among the five suitable for commercial use (Fitzpatrick and Stewart 1968). These two aspen species, comprising approximately 80 percent of the poplar resource in Canada, occur in unmanaged stands, many of which are overmature and decadent.

In spite of the wide distribution and abundance of poplars in Canada, only 5 percent of the estimated allowable annual cut is used; this underutilization is attributed partly to easy availability of conifers in areas closer to mills and partly to certain biological features of the species. However, interest in utilization and management of aspens is increasing not only because of the expected increase in the demand for forest products but also because of the wide ecological amplitude and fast growth rate of aspen.

Various biological aspects of aspens in Canada have been described in recent reports (Maini and Cayford 1968, Shoup *et al.* 1968). This report deals with the silvics and ecology of aspens in Canada, with emphasis on the features considered significant in the management of natural stands.

## TAXONOMY

Only two species of aspen belonging to Section Leuce of the genus *Populus*, namely trembling aspen and largetooth aspen, are native to Canada and the United States. Detailed taxonomic descriptions of these two aspens, which are widely distributed in Canada (fig. 1), have been presented by Maini (1968). Among poplars, these species may be easily recognized in the field by the following morphological characteristics:

### Leafy Condition in Summer

1. Leaf orbicular to broadly ovate or elliptical, glandless. Buds not resinous; leafstalk, at least in upper part, flattened in vertical plane, about  $\frac{3}{4}$  length of blade . . . . . Aspens . . . . 2  
Leaf narrow, lanceolate to ovate, fine-toothed. Leaf stalk about  $\frac{3}{4}$  length of leaf blade, flattened on top. Buds resinous. . . . . Cottonwood and Balsam Poplar
2. Leaf coarsely sinuate-toothed; usually 10 or fewer teeth each side. Buds grayish downy. . . . . Largetooth Aspen  
Leaf finely serrated to crenate; usually 15 or more teeth each side. . . . . Trembling Aspen

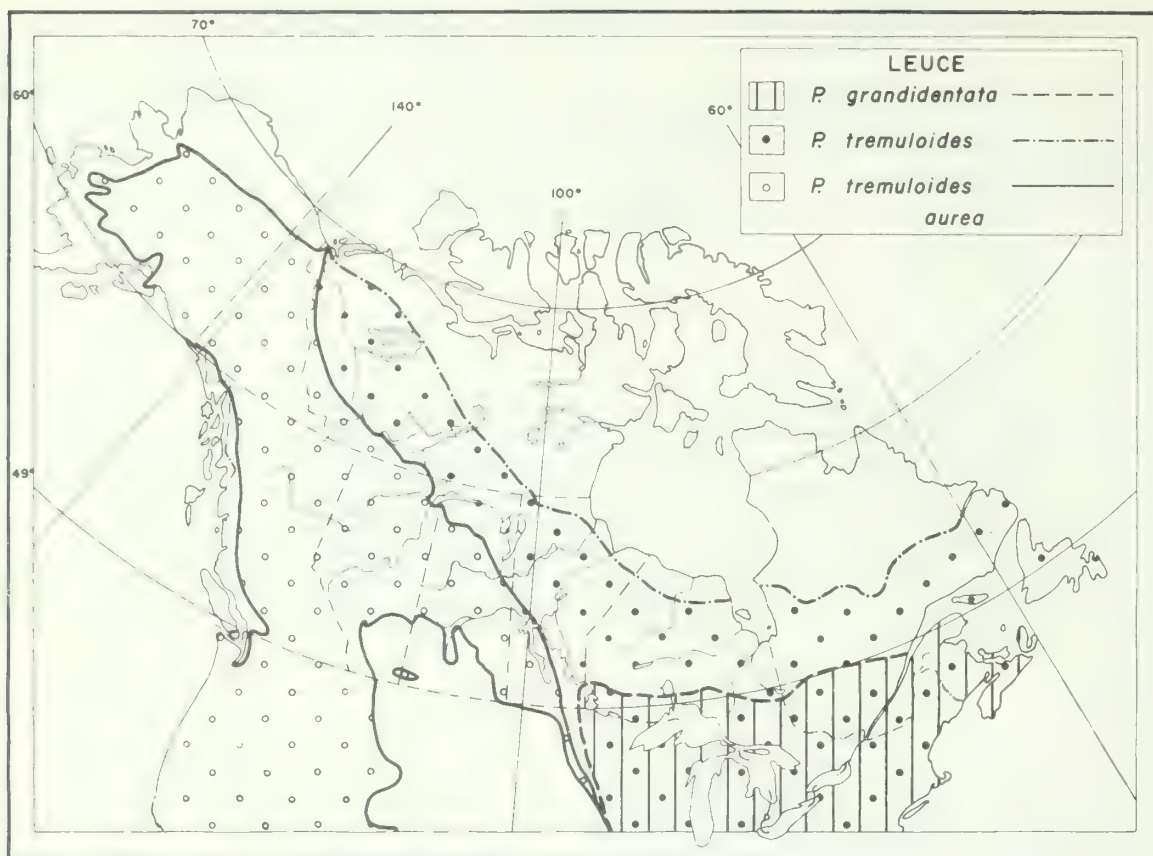


Figure 1. — *Distribution of Populus tremuloides, P. tremuloides aurea, and P. grandidentata in Canada (after Maini 1968).*

There is considerable variation in the size and shape of leaves borne on short, slow-growing lateral shoots and of leaves on vigorously growing long shoots, stem sprouts, and suckers. Only leaves borne on short shoots are reliable for species identification.

### Leafless Condition in Winter

1. Buds nonresinous . . . . . Aspens . . . . . 2  
Buds resinous . . . . . Cottonwoods and Balsam Poplars

2. Buds glabrous, brown, the terminal longer than the subjacent lateral bud. Smooth bark white, gray, or pale green, roots pale brown . . . . . Trembling Aspen  
Buds grayish downy, the terminal and subjacent lateral buds of almost equal length. Smooth bark greenish yellow; roots dark reddish brown.  
. . . . . Largetooth Aspen

A number of forms and varieties of trembling aspen have been reported in Canada (Maini 1968); these distinctions, however, are not made from a silvicultural viewpoint, and even the two aspen species are usually treated in similar fashion.

### ECOLOGICAL LIFE HISTORY

#### Phenology

Aspens are normally dioecious (i.e., male and female flowers are separate and borne on different plants); some floral abnormalities, however, have been reported (Maini and Coupland 1964). Flower buds of aspens swell and extend before the leaf buds and in western Canada the female plants flower and leaf earlier than the male plants. In southern Canada, the aspens flower in early April and leaf in early May. These phenological events are delayed north-

wards and their timing appears to be determined by air temperature. In Ontario, flowering, leafing, and seed dispersal occur about 10 days later in largetooth aspen than in trembling aspen. The considerable variation in the phenology of different clones helps delineate various clones.

### Sexual Reproduction

Aspens start flowering at about 10 years of age and mature trees produce adequate seed crops annually. Good seed crops may be expected every 2 years. During an "average year," for example, a 23-year-old, 33-foot-tall trembling aspen in southern Ontario produced 1.6 million seeds. The seeds are light (2.5 million trembling aspen seeds weigh 1 pound), pear-shaped, and have a tuft of long silky hair attached to the narrow end, enabling them to disperse over long distances. In spite of the enormous quantities of aspen seed produced annually and the ease of germination under controlled conditions (e.g., 80 to 95 percent at room temperature), establishment resulting from seeds under natural conditions is uncommon for the following reasons (Maini 1960, 1968):

1. Short seed viability.
2. The presence of a water-soluble germination and growth inhibitor in seed hair.
3. The occurrence of unfavorable moisture conditions during seed dispersal on upland sites that aspens usually inhabit.
4. The susceptibility of seedlings to high temperatures that occur on soil surface blackened by fire.
5. The susceptibility of seedlings to fungal attack.
6. The adverse influence of diurnal temperature fluctuations on initial seedling growth.
7. The unfavorable chemical nature of some substrates on which the seeds are likely to fall.

### Asexual Reproduction

Rooting of aspen stem cuttings is extremely difficult and one of the major obstacles to mass multiplication of the desirable genotypes. Sprouts from stump and root collar are uncommon, although sprouts from the latter occur somewhat more frequently in largetooth aspen than in trembling aspen.

The most common mode of aspen reproduction is the formation of adventitious shoots on roots (suckers). Suckering following logging in aspen stands has

been attributed to isolation-induced increase in soil temperature (Maini 1968) and to relief from the apical dominance effect.<sup>1</sup> Repeated vegetative reproduction of dioecious aspens has resulted in the formation of male and female clones that range from a few to several hundred trees (Maini 1968) and occupy 0.01 to 3.80 acres of land.<sup>1</sup> From a silvicultural viewpoint, the development of clones is perhaps the most significant biological feature of aspen stands. While a single clone may occupy a particular land surface to the exclusion of others, intermixing of clones is common.

Trembling aspen suckers are borne on roots that range from 0.2 to 2.0 inches in thickness and are located in the upper 2 inches of soil (range: 1.0 to 4.0 inches). The sucker-bearing roots on largetooth aspen range from 0.2 to 4.5 inches in thickness and penetrate to a depth of 3 inches in the mineral soil (range: 1.0 to 7.0 inches).

Although under natural conditions suckering is profuse after various types of disturbances, aging aspen stands reportedly decrease in suckering capacity. The pattern of spatial distribution of clones and the physiology and ecology of root-suckering have been studied under controlled environmental and the field conditions. The studies show a significant clonal variation in suckering capacity (fig. 2), optimum temperature for suckering, and the rate of suckering in the two species of aspen (Maini 1967), and the rootability of newly formed suckers.<sup>1</sup> In the controlled environment, root cuttings from clones that sprouted the most suckers produced the most large suckers. No significant correlation, however, could be established between the size of the clones (from which the root cuttings had been sampled) and the sucker growth or the rooting ability of these root cuttings; clone size was also not related to the soil moisture and the nutrient level of the various sites.<sup>1</sup> Considerable clonal variation in disease susceptibility has also been reported (Wall 1969). The foregoing features indicate that the natural stands of aspen are genetically and ecologically very diverse.

<sup>1</sup> Stenecker, G. A. *Structure, size, and development of trembling aspen* (*Populus tremuloides* Michx.) clones in Manitoba. (Unpublished report, 157 p. 1972.)

75 °F

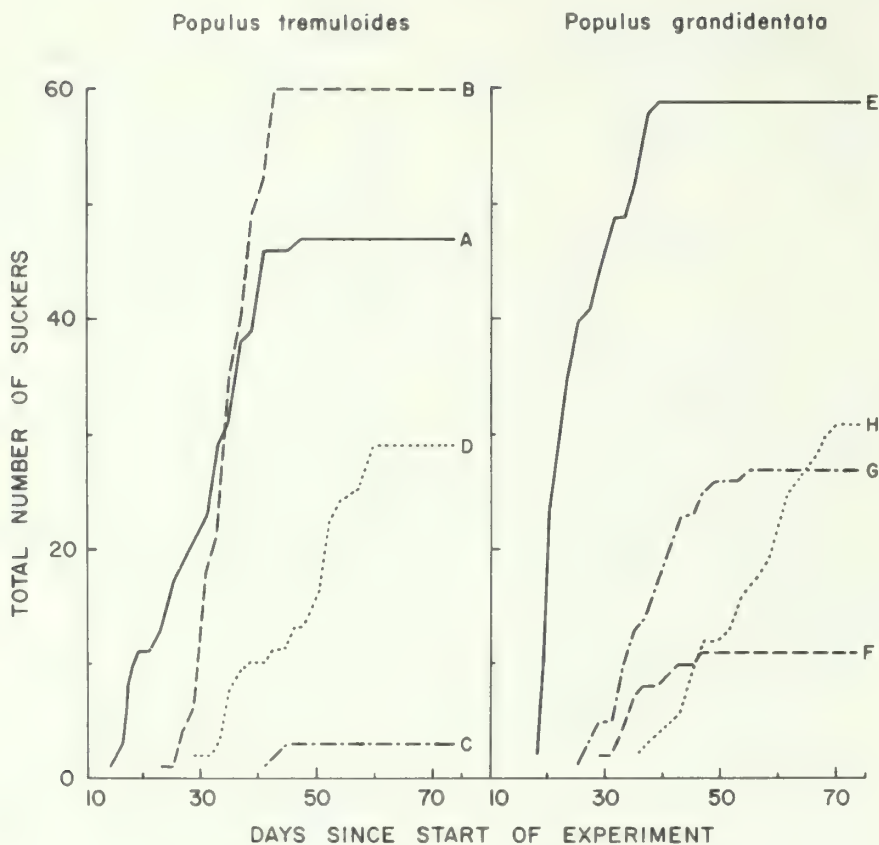


Figure 2.—Variation in sucker formation on root cuttings obtained from four clones of *Populus tremuloides* and *P. grandidentata*, maintained at 75° F.

## EARLY GROWTH

### Stem Growth

Aspens are intolerant to shade and require full sunlight for optimum growth. The suckers may originate singly or in a clump and the height of the dominant shoot in a clump increases with the number of suckers in the clump (Maini 1968). Suckers that initially have a rapid growth rate tend to maintain their dominance (Pollard 1971).

Height growth of young plants was not adversely affected when subjected to various degrees of defoliation, branch pruning, and debudding (Maini 1966, Pollard 1970); these observations suggest that a young stand of aspen suckers may be lightly browsed without any detrimental effects to the future crop.

There is considerable clonal variation in the phenology, growth rate, form, branching habit, and disease susceptibility. Studies by Vaartaja (1960) have demonstrated the occurrence of photoperiod ecotypes in trembling aspen — a feature that one would expect to occur in a widely distributed species.

### Root Growth

Information on initial root growth is scanty due to the paucity of seedlings in nature. However, most new roots develop near the base of suckers and spread laterally in the upper soil layers. Trees of sucker origin can be distinguished from seedlings by a thickening that develops on the distal side of the parent root adjacent to the sucker (Maini 1968). The root system of aspens extends 40 feet or more from the stem base, that of largetooth being located a few

inches deeper than that of the trembling aspen; the former is also less profusely branched and has fewer adventitious roots. Recently Zufa (1971) has successfully rooted aspen by planting succulent suckers in a suitable rooting medium maintained under high humidity.

## STAND DEVELOPMENT AND MANAGEMENT

The intolerant aspens have many features characteristic of a pioneer species. However, most aspen regeneration on cutover and burned forest land is vegetative; i.e., from root suckers. The abundance of aspens in disturbed forest land, which is indicative of their ecologic significance, is determined by the proportion of aspen in the logged or burned forest and the magnitude of disturbance.

A fully stocked stand of aspen, when clearcut (or burned), produces up to 40,000 suckers per acre. However, mortality in young sucker-stands is high and by 30 years of age, the number is reduced to

1,000 to 1,500 stems; at maturity (70+ years), the stocking ranges from 300 to 400 trees per acre. Regeneration of aspen following removal of apparently pure conifer stands is usually from the roots of a few widely scattered individuals.

Aspens grow under a wide range of ecological conditions and are found associated with almost all native trees of Canada. Depending on stand history, the two aspens occur in extensive pure stands, in mixed stands of the two aspen species, in association with conifers, particularly spruce and pine, and with other hardwoods, commonly paper birch. Shrubs and herbs commonly associated with aspen and competing with aspen regeneration include *Symphoricarpos*, *Corylus*, *Alnus*, *Prunus*, *Salix*, *Lonicera*, *Viburnum* and *Pteridium* (Maini 1968).

In one investigation, the height growth of dominant trembling aspen trees was measured in 96 mature stands, located in an approximately 750-mile long south-north transect, extending from 49° and 50° N. latitude (fig. 3). In the south, height growth

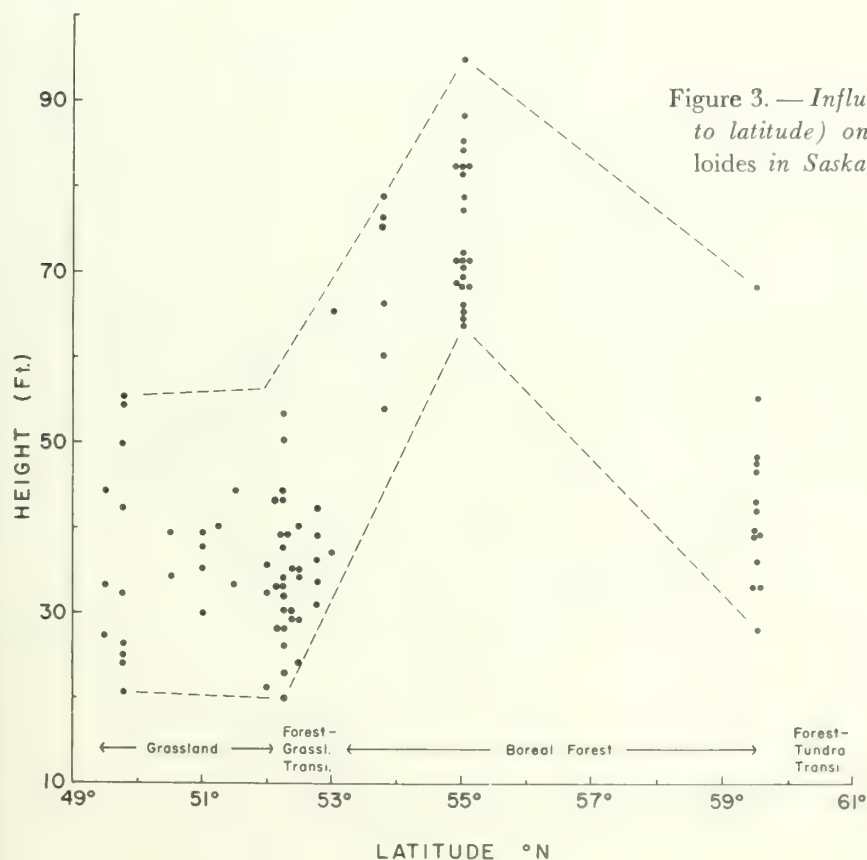


Figure 3. — Influence of climatic gradient (as related to latitude) on height growth of *Populus tremuloides* in Saskatchewan (from Maini 1968).

was apparently limited by inadequate moisture and in the north by unfavorable temperature and edaphic conditions. In Canada, optimum growth of trembling aspen is attained north of the height of land where rivers flow toward Hudson Bay; it is interesting to note that the "Major Poplar Area" in Canada (fig. 4) described by Fitzpatrick and Stewart (1968) also lies in this geographical region.

Several silvicultural techniques have been applied to stimulate aspen suckering and to control competition from associated vegetation. The relative effectiveness of the various treatments has been evaluated by using a "Reproductive Index" (Maini and Horton 1966). Considering the great microenvironmental variations that occur in the surface soils following disturbance in an aspen stand and the tremendous intraspecific variation in the ecologic requirements of aspens, it is not surprising that many clones continue to perpetuate in a given area. Consequently, aspens

have been regarded as weed species, sometimes difficult to eliminate.

Many aspen stands are overmature and decadent. Economic considerations necessitate high grading of clones that have superior growth and low incidence of disease and other defects. This practice is expected to lower the quality of future aspen stands because these clones do not reproduce adequately under a partial canopy. And unless they produce suckers, roots of these superior aspen clones decay within 3 to 4 years after cutting, and so the inferior clones would be perpetuated when the remaining tree canopy is eventually removed by logging or natural fire. The influence of high grading on impoverishment of gene-pool is much more serious in species that reproduce predominantly by vegetative means than those that reproduce by seeds. Therefore, clearcutting is essential to obtain good regeneration of aspens and to conserve a broad genetic base.

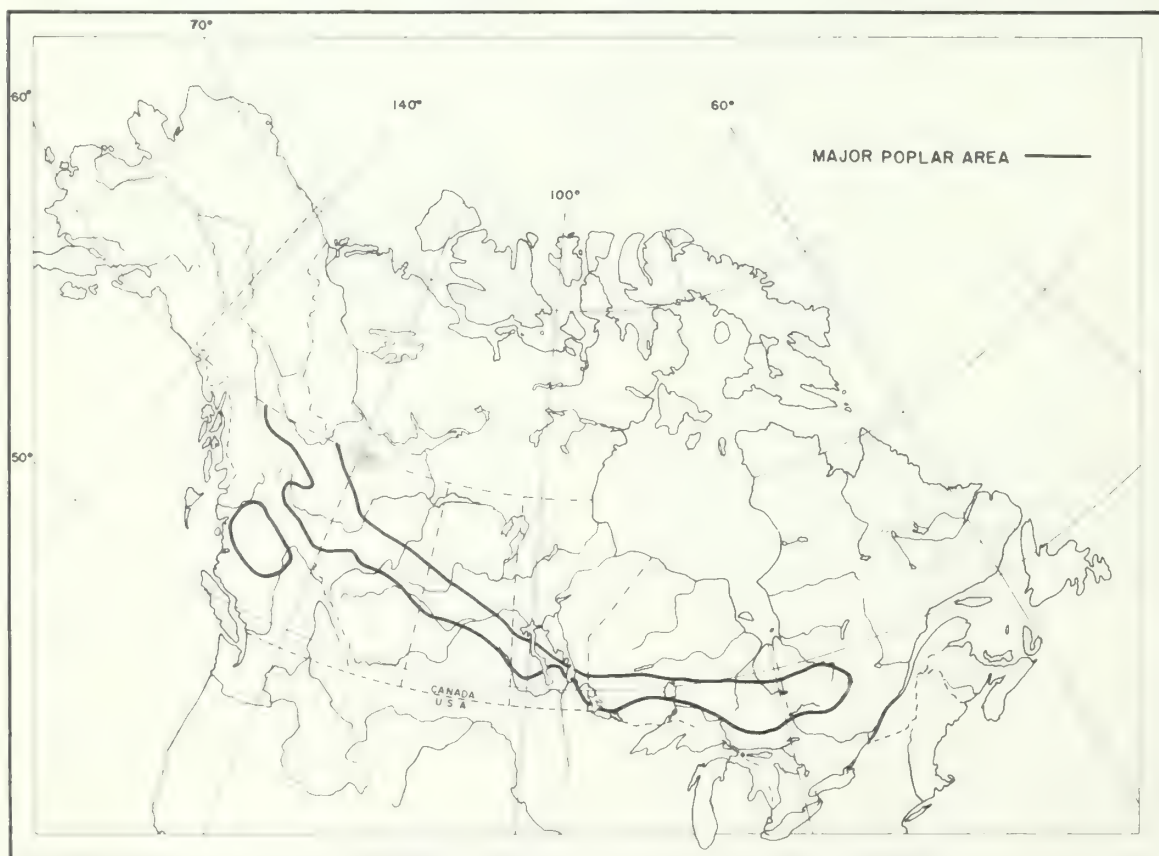


Figure 4. — *Major area of poplar volume, mostly aspens, in Canada (after Fitzpatrick and Stewart 1968).*

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# DISEASES

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**ABSTRACT.**—Reviews literature on the diseases of quaking aspen. Emphasis is placed on the Eastern United States and Canada; related problems in other areas are also included. The future impact of aspen diseases is discussed.

A number of diseases attack aspen throughout its broad range in North America. These diseases in aggregate damage all parts of the tree from roots to foliage. Although many pathogens attack aspen, the major impact results from attacks by relatively few parasitic fungi. Of these, the most important cause various decays and stains that greatly reduce merchantable volumes, especially in older stands. Although they do not normally kill the host tree, these pathogens impose a pathological rotation on aspen producers who must harvest early to minimize losses. The next most important group of pathogens causes cankers on the main bole of the tree. These kill directly by girdling the stem, as well as indirectly by weakening the tissues and predisposing the trees to breakage by wind. Other pathogens, such as leaf-spotting organisms, do some damage but usually are unimportant. The root pathogens have not been investigated to any great extent and, as a consequence, are relatively little known. However, they are not believed to cause any great damage to the aspen type.

Much has been written on the diseases of aspen. Some articles deal with *Populus* in general on a world-wide basis (Berbee 1964, Farmer and McKnight 1967); others are more restrictive in that they deal with limited regions or certain species (Davidson and Prentice 1968, Graham *et al.* 1963, Hepting 1971). The present account will apply primarily to *Populus tremuloides* in the Eastern United States and Canada.

## STEM DISEASES

Among the many stem pathogens, those that cause stain and decay have the greatest direct impact on

wood production. Because of them it is necessary to impose pathological rotation ages as low as 35 to 40 years in some areas. Canker-producing fungi, too, can cause serious damage to aspen stands. Although these fungi are normally confined to local areas of the stem, the entire tree is killed when the bole is girdled by them. Because aspen wood is quickly degraded, the trees killed in this way are usually lost. Most of the other stem diseases of aspen are of lesser consequence.

## Stain and Decay

Stain is a very common defect in the stems of aspen trees. Several conditions are said to be associated with stain; some involve micro-organisms while others do not. Although organisms are frequently associated with discoloration, their role is not understood. Discoloration, which develops in the absence of micro-organisms, has been little studied, and it is not known if pigment production can continue for any length of time. Apparently wounding, which exposes the xylem to the atmosphere, results in pigment production around the wound (Sucoff *et al.* 1967). Xylem killed without being exposed to the atmosphere does not discolor.

Associated with decay columns in aspen are zones of discoloration of varying intensity. Considerable portions of the stem are often discolored. Although the strength of affected tissues is not reduced greatly in the initial stages of decay, the discolored wood increases manufacturing costs for color-sensitive products.

Aspen tissues are known to harbor a number of

different organisms. From xylary tissues, a variety of fungi and bacteria has been identified (Good and Nelson 1962, Thomas *et al.* 1960). Apparently, these different organisms interact in such a way as to follow one another in a successional manner, suggesting that one acts as a precursor for the next. A strong case for the concept of fungal succession in wood was made by Shigo (1967), and a good account of the successional appearance of various organisms in aspen was presented by Etheridge (1961). He found that bacteria were the first organisms to appear, followed by *Cytospora* spp., *Phoma* spp., and *Libertella* spp. Two wood decay fungi, *Corticium polygonum* and *Polyporus adustus*, preceded the common decay fungus, *Fomes igniarius*.

Though stains are very plentiful and occasion much volume loss, the decay-causing organisms are responsible for the greatest volume loss in the aspen type. The bulk of the damage has been attributed to *F. igniarius*. Early in this century there were reports of damage by this fungus to aspens in New England (Weigle and Frothingham 1911) and the Rocky Mountain area (Von Schrenk and Spaulding 1909).

*F. igniarius* is worldwide in its distribution, and on aspen it is known throughout the United States and Canada. In some locations more than 50 percent of the trees on sample plots have been infected (Basham and Morawski 1964, Thomas *et al.* 1960). It is reported to be so prevalent as to mask or conceal rot caused by other fungi (Schmitz and Jackson 1927). Fruiting bodies (fig. 1) are regarded as the most reliable external indication of decay (Basham 1960), and some pathologists have attempted to estimate decay losses in individual trees on the basis of sporophore presence (Hinds 1963, Horton and Hendee 1934, Riley and Bier 1936). Other studies have related damage to tree age (Meinecke 1929, Riley 1952), height (Brown 1934), and diameter (Basham 1960). Evidence conflicts as to the relation between site quality and decay (Wagener and Davidson 1954): both positive correlation (Davidson *et al.* 1959) and negative correlation (Brown 1934) have been reported. Apparently, hosts vary in susceptibility to decay by *F. igniarius* because incidence of this pathogen varied significantly among different aspen clones (Wall 1969). Clone had a greater effect than site on decay incidence.

Few reports agree on which fungus causes the next

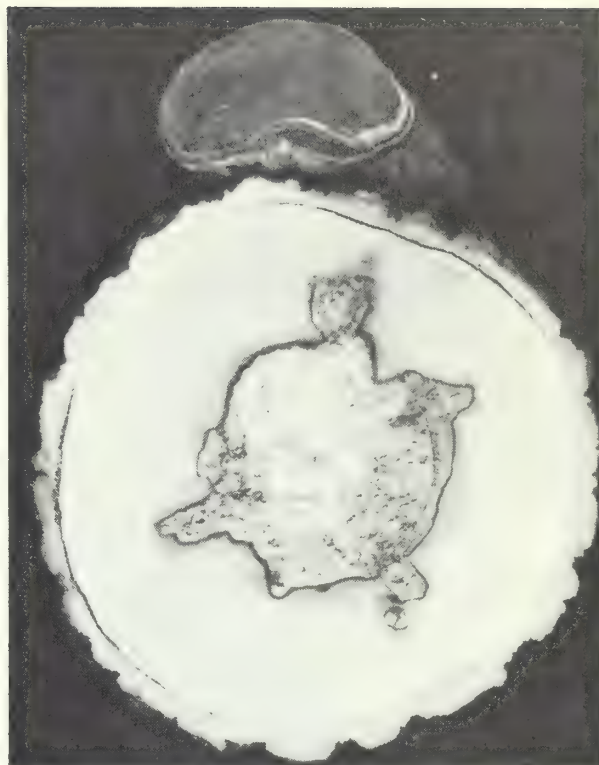


Figure 1. — Cross section of aspen infected by *Fomes igniarius*.

greatest amount of damage after *F. igniarius*. Basham (1958) isolated *Radulum casearium*, *Corticium polygonum*, and *Pholiota adiposa* most frequently from yellow stringy trunk rot in the Upper Pic Region of Ontario. From butt rot in the same region, he isolated *Pholiota spectabilis*, *Armillaria mellea*, *Radulum casearium*, *Pholiota adiposa*, and *Collybia velutipes*. In northern Michigan and Wisconsin, Anderson and Prielipp<sup>1</sup> found *R. casearium* and *A. mellea* to be the most abundant decay-causing fungi on aspen. In Colorado, Davidson *et al.* (1959) isolated *Crytochaete polygonia* most frequently even though *F. igniarius* caused the greatest volume loss.

### Cankers

Cankers are among the most common disease problems on aspen. Although there have been few comprehensive assessments of the damage caused by

<sup>1</sup> Anderson, Gerald W., and Prielipp, Donald O. Decay and stain of quaking aspen in northern Michigan and Wisconsin. (Unpublished manuscript.)

the many different canker-producing organisms, their impact is considerable. Some canker-causing fungi produce slow-growing, persistent infections; others become established and kill the host within a relatively short time. Regardless of their rate of action, the net effect is loss of part or all of the diseased stem for most purposes.

Because many cankers are similar in appearance, the task of distinguishing between the various canker types on aspen can be difficult. Where several similar types occur in the same geographic area, it can be next to impossible to differentiate them in the field (table 1). Often identification can be made only by isolating the causal organism and demonstrating its pathogenicity by inoculating healthy trees.

### Hypoxylon Canker

In many areas hypoxylon canker is regarded as the most serious aspen disease. It has been reported from a number of locations throughout most of the range of quaking aspen in the United States and Canada, but it has not been found in Alaska and adjacent portions of the Yukon territory. The disease occurs, too, on *P. tremula* in Czechoslovakia and Russia.

It has been estimated that this disease kills 1 to 2 percent of the aspen each year (Anderson 1964). Caused by *Hypoxylon mammatum* (*H. pruinaum*), this canker disease is manifested by rapid invasion and early death of host tissues. While callous tissue may form along the margin of some cankers, and occasionally a tree will appear to recover from infection, in the vast majority of cases, once established,

the fungus overwhelms the defense mechanism of the host (fig. 2). Mortality occurs as a result of stem girdling or wind breakage at the point of infection.



Figure 2.—*Hypoxylon* canker on aspen at the base of a dead branch.

Table 1.—*Summary of poplar canker diseases, causal organisms, and major areas of occurrence.*

Canker	Fungus	Main region
Hypoxylon canker	<i>H. mammatum</i>	Rocky Mtns., Lake States, Canada
Cytospora canker	<i>C. chrysosperma</i>	United States and Canada, general
Dothichiza canker	<i>D. populea</i>	Widespread
Sooty-bark canker	<i>Cenangium singulare</i>	Rocky Mountains
Neofabraea canker	<i>N. populi</i>	Canada
Nectria canker	<i>N. galligena</i>	United States and Canada
Shoot blight	<i>Venturia</i> spp.	Canada and northern United States
Ceratocystis canker	<i>C. fimbriata</i>	Minnesota
Pezicula canker	<i>P. ocellata</i>	Canada

Adapted from: Hepting, George H. Diseases of forest and shade trees of the United States. USDA Forest Serv. Agr. Handb. 386: 393. 1971.

Although the mode of infection is not known, incipient infections first appear as slightly depressed tan to yellowish areas in the host bark (Bier 1940). Frequently they are associated with branch stubs or stem abnormalities. It has been reported that insects are instrumental in transmission of the fungus by creating infection courts (Graham *et al.* 1963) and that insect control would reduce infection (Graham and Harrison 1954). However, other investigators report no association between insects and canker distribution (Ewan 1959).

Canker prevalence and host density are correlated; low-density stands have proportionally more infection than high-density stands (Anderson and Anderson 1968). Prevalence also has been related to age of the host and geographic location (Anderson and Anderson 1969). Stand composition, too, has been suggested as being related to canker prevalence, but the association is not clear. Evidence has been presented to show that new infections are established in a "wave year" pattern (Schmiege and Anderson 1960). Whether environmental factors or vectors occasion this phenomenon is unknown.

To minimize losses due to hypoxylon canker, the forest manager should maintain fully stocked stands. Stands in large blocks are preferred to reduce edge effect around margins where hypoxylon canker infection is frequently high. In addition, pure stands should be encouraged. Sanitational removal of infected stems seems of little value.

### **Nectria and Ceratocystis Cankers**

Nectria and Ceratocystis cankers are being discussed together here because of confusion that exists as regards their pathogenicity on aspen. Historically, target-shaped cankers on aspens have been called Nectria cankers (fig. 3) and are assumed to be caused by *N. galligena* even though the conspicuous reddish-colored perithecia borne by this fungus have seldom been observed on aspens. Recently, investigators have begun questioning this assumption and suggesting that some other fungi may be involved. Accordingly, isolation and inoculation work have been done to clarify the matter (Manion and French 1967, Wood and French 1963). It has been shown that *Ceratocystis* spp. are associated with infections of this type. *C. fimbriata* has been recovered from these cankers in a number of locations — Manitoba and Saskatchewan (Zalasky 1965), Colorado (Hinds 1964), Min-



Figure 3. — "*Nectria*" canker on quaking aspen.

nesota (Campbell 1960, Hinds and Anderson 1970), and Pennsylvania (Wood 1964). These cankers seldom cause mortality but do cause volume losses.

Although definite associations have been made between cankers and apparent causal organisms, additional data are needed to establish conclusively the primary pathogen. Further work being planned or underway may clarify this situation and identify the organism responsible for causing these "nectria"-type cankers. While it is too early to assess this work, it may be that more than one fungus is involved.

### **Cenangium Cankers**

A prominent sooty-bark canker of aspen in the Central Rocky Mountains is caused by *Cenangium singulare* (Davidson and Cash 1956). It is common in Colorado where it does a great deal of damage (Hinds 1964). Infection apparently takes place through fresh wounds (Hinds 1962). Symptoms in-

clude a blackened bark that remains intact over the infected area. Vertical spread is rapid, and cankers 15 feet in length have been reported. Limited sporulation may occur after 3 to 5 years but becomes most abundant after the tree is killed. The fungus has been found on aspen in a number of locations in Minnesota (Hinds and Anderson 1970); but in these areas it appeared to be saprophytic on the bark. Why the fungus does not cause damaging perennial cankers in Minnesota, as in Colorado, is unknown.

### Cytospora Canker

*Cytospora chrysosperma* and its perfect stage, *Valsa sordida*, occur throughout the world. This fungus can cause canker on aspen (Schreiner 1931) but is not regarded as a primary pathogen (Christensen 1940). The fungus is a normal inhabitant of aspen bark and causes cankers only after the host has been stressed (Long 1918). Fire, drought, frost, leaf diseases, and off-site location have been mentioned as factors that predispose trees to infection (Povah 1921, Treshow and Harward 1965). Reducing the water content of the host tissues also increases its susceptibility (Müller-Stoll and Hartmann 1950). It is suggested that this may operate partly through the mechanism of tannin deposition (Bloomberg and Farris 1963).

The disease is most serious on young trees, transplants, and aspen hybrid material (Bloomberg 1962, Huppel 1964). Cankers appear as sunken brown areas that eventually girdle the stem. On older stems with rough bark, cankers are difficult to identify until spore tendrils appear (Boyce 1961). Maintaining trees in a normal vigorous condition is the best means of avoiding losses from this fungus.

### Dothichiza Canker

Dothichiza canker, caused by *D. populea*, occurs in the eastern United States and Canada (Waterman 1957). This appears to be an endemic disease that infects a number of poplars and their hybrids. Infection has been found on quaking and bigtooth aspen (Honey 1944). It is regarded as a disease of young or weakened trees and trees growing in plantations. The disease has not been reported in vigorous natural stands. In Europe, where the fungus is common, it is considered one of the most dangerous pathogens of poplar plantations.

### Neofabraea Canker

A little-known disease, Neofabraea canker, caused by *N. populi*, has been reported from Ontario (Thompson 1939). Thus far, it has not been found in the United States. Only young trees are infected, and these on the lower bole. Cankers may be up to 6 inches long, with spores produced on the bark surface.

### Wetwood

Wetwood is a condition in which the central heartwood of the tree has a darker color, higher pH, and is more moist than in a normal tree. Little-known bacteria are associated with this condition (Hartley and Davidson 1950). An isolate of *Corynebacterium humiferum* obtained from *Populus nigra* has been transferred successfully to *P. tremuloides* (Seliskar 1952), suggesting that a bacterium may have more than one host. No estimate of the amount of damage resulting from wetwood infection of aspen is available, but for some uses the discoloration associated with this condition probably causes increased processing costs. Losses also result from tissue collapse, which often occurs when these infected materials are being dried.

### Rough Bark

The surface of normal healthy aspen stems remains smooth even as the tree grows and increases in girth. However, because of injuries, most stem surfaces are broken and fissured, a condition that is referred to as rough bark. Fungi, lichens, and mechanical wounding can initiate this condition, which is manifested as rough bands of varying width that extend all or part way around the stem. *Diplodia (Macrophoma) tumefaciens* is reported to be the primary cause of rough bark (Kaufert 1937, Zalasky 1964). Infected trees are not known to suffer from reduced growth or loss of vigor.

### LEAF DISEASES

In most areas, leaf diseases are not considered important in aspen management (Christensen *et al.* 1951). While a number of fungi infect aspen leaves, they do not have significant impact on fiber production. In the future, however, if the supply of aspen becomes more critical or management practices are

modified so that younger and thus smaller stems are utilized, the impact from foliar diseases may be viewed differently. At present there are no known controls for these pathogens.

### Leaf Spots

As might be expected with a tree having such wide geographical distribution, a number of leaf diseases attack aspen. One of the most prevalent is a leaf spot caused by *Marssonina populi*. Under epidemic conditions it can cause premature defoliation. Repeated attack reduces growth and may cause dieback (Mielke 1957). Apparently aspen has a wide range of susceptibility to infection; some clones are heavily attacked while others in the same vicinity have little or no infection.

Another common leaf disease caused by *Venturia tremulae* (Dance 1959) is manifested as angular black spots that increase in size until the leaf dies. A similar disease on balsam poplars is caused by *V. populina* (Dance 1961). The fungus is able to grow through the leaf petiole into the stem and damage tissues beneath. If infection occurs at the top of a tree, it can kill and darken the shoot, which withers and becomes bent (fig. 4). This "shepherd's crook," as it is sometimes called, is common, particularly in younger stands. A similar leaf disease syndrome in Wisconsin has been attributed to *Colletotrichum gloeosporioides* (Marks *et al.* 1965).

The "ink spot" disease of aspen foliage is common in some areas (Pomerleau 1940). This disease is caused by two or more species of *Ciborinia* (*Sclerotinia*). The infected spots on the leaves turn black during the summer, and this material falls free, leaving a hole in the leaf. Although small trees may be killed by heavy infection, older trees normally survive.

Another leaf spot of aspen is caused by *Septoria musiva* (Thompson 1941), a fungus that also incites stem cankers on hybrid poplars. The symptoms are discrete necrotic lesions. Spores are produced on both leaf surfaces throughout the growing season.

### Leaf Rust

Several leaf rust fungi belonging to the genus *Melampsora* have been reported on *Populus*. One of



Figure 4. — *Venturia tremulae* infection on aspen, a disease that is particularly damaging to young trees.

the most common, *M. medusae*, has been reported on aspen throughout much of the United States east of the Rocky Mountains (Anon. 1960). *M. abietis-canadensis* occurs in the New England area and westward and *M. albertensis* is reported from New Mexico northward through Canada to Alaska. These fungi have life cycles that include aspen and a coniferous host. Although they can cause discoloration and death of quaking aspen leaf tissue, they more commonly damage hybrid aspens.

### Powdery Mildew

Although little mentioned in the literature, powdery mildew does occur on aspen. *Erysiphe cichoracearum* is common in the West (Meinecke 1929) and *Uncinula salicis* is reported to be widespread (Anon. 1960). While infection by these organisms can be quite conspicuous on the leaves, any damage resulting is probably of minor importance.

## Leaf Virus

An innocuous leaf-spotting disease of aspens that may be virus-caused occurs in Canada (Boyer 1962, Boyer and Navratil 1970). Electron microscopy has revealed some virus-like aggregates in these tissues. The disease has been transmitted by insects and by budding. Initial symptoms are chlorotic spots that become raised, turn brown, and collapse. Red pigments frequently develop in and around the lesion before the tissue dies. The affected leaves are often distorted from mechanical stress on the remaining living tissue.

## FLORAL DISEASES

### Catkin Deformity

A catkin deformity, caused by *Taphrina johansonii*, occurs on aspen east of the Great Plains (Anon. 1960). The disease is manifested by carpel enlargement. Because aspen is normally regenerated by root suckering, this disease is of little consequence except to plant breeders who are concerned with aspen seed production.

## ROOT DISEASES

Very little is known about the root diseases of aspen, probably more from lack of study than freedom from diseases. Undoubtedly, some of the decay fungi that have been reported to cause damage in aspen stems can cause root damage too. *Armillaria mellea* is one of the few fungi reported to cause root rot on aspen (Schmitz and Jackson 1927). Some mycorrhizal fungi (*Cenococcum graniforme*, *Leccinum aurantiacum*, and *L. scabrum*) have been reported on aspen roots (Trappe 1962). Nothing is known about the effects of soil compaction, but this undoubtedly would affect root development.

## NONBIOTIC

### Weather

Within its primary range, aspen is little affected by normal climatic conditions. Damage does result, however, from extreme weather. Strong wind and wet, heavy snow or sleet can break branches or whole trees. Hail storms may produce bark bruises that could serve as infection courts for pathogenic organisms. Prolonged drought may reduce growth, but probably

does not cause death except for very small trees under unusually severe conditions. Frost crack and sunscald are found in many areas. The latter is particularly noticeable in recently disturbed locations where sunlight strikes previously protected stems.

## Fire

Fire favors aspen establishment by reducing competition through killing of the overstory and stimulating suckering. Subsequent fires, however, can injure or kill established stands. Repeated burning can reduce aspen site index by 6 to 25 feet and make such reburned areas nonproductive for future aspen management (Stoeckeler 1948).

## FUTURE OUTLOOK

None of the presently known aspen diseases are of the catastrophic type likely to assume epidemic proportions. Therefore, aspen diseases probably will continue to exert the same impact as in recent years. The exception would be if a foreign pathogen to which aspen had little inherent resistance were introduced into North America. Barring that eventuality, it should be possible to predict reasonably well the types of losses that will occur.

In the future we may find that leaf diseases cause more damage than is assumed at present. Our present assumptions in this regard are not well substantiated, and further research might demonstrate that these diseases are important. This could be true especially if short rotation with mechanized harvesting is practiced. Root problems, too, might be important. Thus far they have not been investigated to any extent.

Perhaps the greatest long-term impact from aspen diseases will be on distribution of the type itself. In some areas growth of aspen now exceeds harvest. Where there is also a disproportionate amount of the type at or near the pathological rotation age, it is only a matter of time before much of this material will be too decadent for economical harvest. When that happens and owners disregard these stands in future management plans, the trees will continue to increase in diameter and height while decay is destroying additional wood fiber. Eventually some of these trees may reach 100 or more years of age. Because the stands will open gradually, the result may be type conversion, since the understory of other species often will

take over the site. For that reason, we are in danger of losing untold acres of aspen type unless we can increase the rate of harvest or raise the pathological rotation age by reducing the impact of disease.

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# INSECTS

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**ABSTRACT.**—Insects influence the aspen forest through defoliation, boring, girdling, gall making, and sucking plant juices. The impact is not well understood but in some cases may be beneficial. The most prominent insects are the forest tent caterpillar, the large aspen tortrix, the poplar borer, and the insects attacking aspen suckers. An increased awareness of the many kinds of insects found throughout the life of an aspen stand will improve the forester's management decisions.

Aspens are host to a wide variety of insects. Davidson and Prentice (1968) report the Canadian Forest Insect and Disease Survey has recorded at least 300 species on trembling aspen alone. Many of these apparently have little impact upon the aspen forest, but the role of some is not yet understood. Some are obviously deleterious; others may be beneficial. I shall discuss only those that are most frequently encountered or that severely damage aspen trees. For more detail, see Graham *et al.* (1963) and Shoup *et al.* (1968).

## DEFOLIATORS

The foliage-feeding insects of aspen belong mainly to the orders Lepidoptera (moths and butterflies) and Coleoptera (beetles). The most spectacular defoliator of aspen is the forest tent caterpillar, *Malacosoma disstria* (Hübner). This native insect has defoliated aspens and other broadleaved species over areas as large as 100,000 square miles (Davidson and Prentice 1968). Its estimated impact on the aspen ecosystem ranks above all forest insects in the north-central United States (Addy *et al.* 1971). Outbreak patterns have been described by Hodson (1941), Hildahl and Reeks (1960), and Sippel (1962). High populations appear suddenly at approximately 10-year intervals following an increase in annual cyclonic passages (Wellington 1952). These outbreaks normally persist for 2 to 3 years. However, heavy infestations have occurred in the same stands for 6 consecutive years in the International Falls, Minnesota, area (Witter *et al.* 1972) and for 7 years in Alberta (Shepherd and Brown 1971). Outbreaks may end as abruptly as they began; decline has been attributed to low hatch due to frost, starvation of larvae after hatch due to frozen foliage, and freezing (Prentice 1954, Blais

*et al.* 1955, Hildahl and Reeks 1960, Gautreau 1964, Smith and Raske 1968). Starvation may occur when the number of insects increases so rapidly as to exhaust the food supply before caterpillars are fully grown.

Complete defoliation of the aspens as well as the understory shrubs commonly occurs in June. Heavily defoliated trees refoliate by the end of July. Tree mortality has not been widespread. Locally, stands may sustain 20- to 80-percent mortality on poor sites during drought years (Duncan and Hodson 1958, Barter and Cameron 1955, Ghent 1958), but more commonly some branch mortality and reduced diameter growth occur (Batzer *et al.* 1954, Hildahl and Reeks 1960, Rose 1958, Dils and Day 1950). Growth may be reduced about 2 cords per acre (Hildahl and Reeks 1960, Duncan and Hodson 1958). Growth is significantly reduced 1 year beyond the cessation of defoliation, but the third year after defoliation in stands heavily defoliated 3 successive years growth on dominants increased. *Hypoxylon* and *Nectria* fungus infections increased with intensity of defoliation (Churchill *et al.* 1964). During outbreaks the large numbers of caterpillars and the denuded trees are a nuisance in resort areas. However, the effects of forest tent caterpillar outbreaks are not entirely negative. Where there are understory conifers such as balsam fir, heavy defoliation of the overtopping aspen has resulted in a 20-percent increase in radial growth of the balsam fir (Froelich *et al.* 1955).

More than 40 species of insect parasites attack the forest tent caterpillar. One of the flesh flies, *Sarcophaga aldrichi* Parker, is the most abundant; living maggots are deposited on cocoons and bore into the body of the caterpillar prepupae or pupae. The small

tent caterpillar larvae are susceptible to nuclear and cytoplasmic polyhedrosis viruses (Bird 1969), and epizootics in forest tent caterpillar populations have been introduced artificially (Stairs 1965).

Another defoliator found in outbreaks over large areas is the large aspen tortrix, *Choristoneura conflictana* (Walker). Infestations covering 10,000 square miles have occurred in Manitoba, Saskatchewan, and interior Alaska, and nearly 2 million acres of gross land area in Minnesota. Feeding by the tortrix larvae is first noticeable in spring, although some inconspicuous skeletonizing occurs soon after hatching in August just before hibernation. Spring feeding may destroy the buds when populations are high, but generally defoliation takes place in May and June when larvae feed openly on leaves tied together by webbing. The life history of the large aspen tortrix is described by Prentice (1955), Wickman (1963), and Beckwith (1968). Although this insect will feed upon a number of broadleaved trees, large increases in populations require a diet of quaking aspen (Beckwith 1970). Outbreaks normally collapse in 2 to 3 years in any particular area. Little mortality of aspen has been reported from large aspen tortrix defoliation, the principal effect being growth reduction. Tortrix larvae are fed upon by a variety of warblers and grosbeaks. Many species of parasites attack the large aspen tortrix. Hibernating larvae may be infected by a fungus and larger larvae may be attacked by virus (Beach 1970).

A leaf tier often associated with large aspen tortrix infestations is *Sciaphila duplex* (Walsingham) (McGregor 1967). Other aspen leaf tiers are *Epinotia criddleana* Kearfott (Kusch 1967), *Anacampis innocuella* (Zeller) (Miller 1955), *Pseudoexentera oregonana* Walsingham (Wong and Melvin 1967), *Compsolechia niveopulvella* (Chambers) (Henson 1958), and *Enargia decolor* Walker (Beach 1970), to name but a few. Other lepidopterous defoliators of aspen are the Bruce spanworm *Operophtera bruceata* (Hulst) (Brown 1962) and *Lobophora nivigerata* Walker (Smereka 1960). Lindquist and Miller (1969) have a key to common lepidopterous larvae feeding on aspen.

Three species of leaf-rolling sawflies belonging to the genus *Pontania* are found in some local outbreaks in the Lake States. The pale green larvae fold the leaf margin and the injured portion becomes black-

ened (Christensen *et al.* 1951), other sawflies of the genus *Platycampus* Schiodte chew holes in leaves (Wong 1957). As with the previously mentioned defoliators, the main effect is the reduction of growth.

Although their feeding characteristics are different from the defoliators mentioned so far, the lepidopterous leaf miners reduce the photosynthetic area of leaves. The more common of these are the aspen leaf miner *Phyllocnistis populiella* (Chambers) (Condrashoff 1964), which produces meandering mines in the epidermal layers of the leaf surface, and the aspen blotch miners *Lithocolletis tremuloidiella* (Braun) and *L. Salicifoliella* Chambers, which cause irregularly shaped blotchy mines (MacAloney and Ewan 1964, Martin 1956). Similar injury is caused by a leaf-mining sawfly *Messa populifoliella* (Townsend) (Underwood and Titus 1968). Heavy attack may cause premature dropping of the foliage.

Beetles that defoliate aspens are the aspen leaf beetle *Chrysomella crotchii* Brown (Smereka 1965), the cottonwood leaf beetle *C. scripta* F., and the introduced species *C. tremulae* (F.) and *C. interrupta* F. (Christensen *et al.* 1951). These have feeding habits similar to the American aspen beetle *Gonioctena americana* (Schaeffer) (Rose and Smereka 1959) and the gray willow leaf beetle (*Galerucella decora* (Say) (Davidson and Prentice 1968). Leaf beetle larvae skeletonize the lower surface of leaves. The adults are general feeders.

## BORERS

The wood-boring insects that attack aspen are principally beetles belonging to the families Cerambycidae (roundheaded borers or longhorned beetles) and Buprestidae (flatheaded borers or metallic beetles). Some borers found in aspens belong to other orders, such as a clear-wing moth of the genus *Aegeria* and a twig-boring sawfly, *Janus abbreviatus* (Say).

The most serious wood borer in aspen is the poplar borer, *Saperda calcarata* Say. The larva of this largest of all North American members of the genus produces tunnels. As a result, wind breakage increases and lumber and veneer are degraded. As much as 64 percent of all mature trembling aspen may be attacked (Graham *et al.* 1963). The tunnels serve as infection courts for wood-rotting fungi, and in Michigan most hypoxylon cankers were associated with

poplar borer and other borer attack (Graham and Harrison 1954). Successful borer activity is evidenced by the accumulation of ejected fibrous frass and streaks of varnish-like dried sap on the bole beneath the ejection openings.

Poplar borer numbers seem to increase during dry years (Graham and Mason 1958). Successful attacks are always concentrated in individual trees or small groups of trees distributed unevenly throughout the stand. Inasmuch as no differences have been observed in growth rate or size between adjacent attacked and unattacked trees, Peterson (1948) has suggested that initial attack occurs randomly, and successive generations attack the same tree. Graham *et al.* (1963) reported that certain trees growing in exposed positions are likely to be attacked several times during years when beetles are especially numerous. Borer infestations tend to vary directly with stem diameter and inversely with stocking (Ewan 1960). Periodic removal of infested trees proved worse than no cutting because the reduction in stand density resulted in more infestations (Peterson 1948). Apparently, the best practice would be to maintain well-stocked stands and clearcut them at maturity.

The root-boring saperda, *Saperda calcarata adspersa* Felt and Joutel, feeds on the phloem and surface of the sapwood on the trunk near the ground (Graham *et al.* 1963). This may be the same species reported by Wong *et al.* (1963) in Manitoba and Saskatchewan.

Several other roundheaded borers commonly occur in sucker stands and on branches of larger trees. The poplar gall saperda, *Saperda inornata* Say, produces globose galls as a result of oviposition incisions in the bark (Nord *et al.* 1972a). As a result of the larvae boring into the wood, growth ceases and susceptibility to wind breakage increases. Another longhorned beetle, the poplar branch borer, *Oberia schaumii* LeConte, attacks larger suckers as well as tree limbs (Nord *et al.* 1972b). Site quality appears not to be significant in attack by these insects. The recommended practice to minimize damage by these beetles is to achieve and maintain maximum density of vigorous aspen regeneration (Myers *et al.* 1968).

The bronze poplar borer *Agrilus liragus* Barter and Brown, one of the flatheaded borers, often weakens and kills aspen by attacking the branches and stem

(Barter 1965). The zigzag galleries disrupt the normal translocation of nutrients. Any weakening factor such as forest tent caterpillar defoliation, hypoxylon canker, wind damage, suppression, etc. increases a tree's susceptibility to attack and enhances borer survival. Graham and Harrison (1954) maintain that *Agrilus* beetles are beneficial because they attack weakened trees and thin the stand.

Another *Agrilus* beetle is the aspen root girdler, *Agrilus horni* Kerremans. The larva bores from the bark on the trunk near the ground to the root, then back to the stem, making a spiral gallery that girdles the sucker (Nord *et al.* 1965).

Several other Buprestids attacking aspen are the flatheaded appletree borer *Chrysobothris femorata* (Olivier), the Pacific flatheaded borer *C. mali* Horn, and the flatheaded aspen borers *Dicerca callosa* Casey, *D. tenebrica* Kirby, *D. divaricata* (Say), and *Poecilognathus cyanipes* (Say). These insects are not serious pests in well-managed stands.

The poplar and willow borer *Sternochetus lapathi* (L.) is a weevil that riddles the stem with galleries when young larvae bore from the outer sapwood toward the center of the stem. Broken places in the bark through which the larvae push their frass and knotty gall-like swellings are characteristic of attack. Planted trees are particularly susceptible. This insect is found from the east to the west coasts of North America on both sides of the Canadian-U.S. border (Harris and Coppel 1967).

## SUCKING INSECTS

Two common galls on aspens are caused by aphids. The poplar vagabond aphid *Mordwilkoja vagabunda* (Walsh) causes a peculiar curled and twisted convolution of leaves up to 2 inches in diameter at the tips of twigs. Another large gall caused by mites commonly follows severe infestations by the forest tent caterpillar. Poplar petiolegall and twig gall aphids of the genus *Pemphigus* produce swellings on leaf petioles of aspens. The speckled poplar aphid, *Chaitophorus populifoliae* (Fitch), and the spotted poplar aphid, *Aphis maculatae* Oestlund, are commonly found on expanding leaves of aspen suckers. Heavy populations may cause increased forking of the stem (Osgood 1963). A common aphid on bigtooth aspen

suckers is *Pterocomma populifoliae* (Fitch) (Sanders and Knight 1968).

Several species of leafhoppers belonging to the genera *Idiocerus*, *Oncometopia*, *Macropsis*, *Oncopsis*, and *Agallia* may be found causing browning of leaves and slit-like ruptures in the bark of twigs (Smereka and Lejeune 1953). Several species of scale insects are found on aspens, one of which is the familiar oystershell scale, but damage is normally limited to trees growing on poor sites or suffering from excessive competition (Graham *et al.* 1963).

## IN CONCLUSION

Other insects not discussed here may occasionally be found in aspen stands. However, even where the identity and biology of insects are known, the role they play throughout the life of the stand is not well understood. Some may attract more attention than they deserve, while others may deserve more attention than they command. The impact of some of the more prominent insects of aspen (such as the forest tent caterpillar, the large aspen tortrix, the poplar borer, and the many insects attacking aspen suckers) needs to be quantified. An increased awareness of the many kinds of insects found in aspen forests and their interactions with the trees, shrubs, herbs, and other biota, along with the management objectives, should improve the forester's ability to decide his course of action.

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# BREEDING AND ESTABLISHMENT — AND PROMISING HYBRIDS

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**ABSTRACT.** — Methods for breeding aspen and for successful plantation establishment, and several promising aspen hybrids are described. By cutting flowering branches from aspen in the winter and forcing them indoors in ice water, 150 to 300 seeds per catkin pollinated can be produced. Establishing aspen plants requires minimizing sod competition. Mechanical cultivation (the only method found satisfactory) produced 2-year average heights of 8 feet for some planted materials. Improved materials of native aspens, *Populus tremuloides* Michx. and *P. grandidentata* Michx., are described as well as native aspens hybridized with Asiatic and European aspens. The more promising interspecific hybrids described include *P. tremuloides* crossed with either *P. tremula* L. (diploid or tetraploid) or *P. davidiana* Dode, and *P. grandidentata* crossed with either *P. alba* L. or *P. x canescens* Sm.

Breeding work with aspens (section *Leuce*) in North America has been a novelty until recent years. The earliest work was done by such pioneers as Dr. Carl Heimburger, Dr. Scott Pauley, Dr. Ernest Schreiner, and Dr. Philip Joranson at a time when aspens were considered weeds. Most of the work by the above-named men included work with poplars to a greater or lesser degree. The foresight of these pioneers is still not fully appreciated by the practical field man.

The program on which this paper is based originated with work by Joranson at Beloit College in 1953. In 1954 Dr. Joranson moved to The Institute of Paper Chemistry, where an industry-sponsored research program for the improvement of aspens in the Lake States was initiated. The program continued under Joranson's direction until 1959, and has since been directed by Dr. Dean W. Einspahr. Of the current aspen breeding programs, the program at The Institute of Paper Chemistry and that at the Southern Research Station, Maple, Ontario, Canada, (now under the direction of Dr. Louis Zufa who succeeds the retired Dr. Carl Heimburger) are the most comprehensive and active in North America.

The worth of aspen should have been fairly well defined in the previous papers submitted to this

symposium. The purpose of this paper then is to take the reader from the germ cell to the established tree in the field. To do this the author draws heavily on his experiences since 1960 with The Institute of Paper Chemistry (IPC). A number of publications (International: FAO, International Poplar Commission 1958; Strothmann and Zasada 1957; Slabaugh 1957; Farmer and McKnight 1967; Einspahr and Winton 1972) have been published containing considerable information on the life cycle and breeding of aspen. Because of the nature of this paper and the previously mentioned publications, the author has chosen a general approach and refers the student of the subject to the more detailed papers.

## BREEDING OBJECTIVES

Basically, the objective of all *Populus* spp. breeding programs is to produce more wood per unit area in a given time, and of a quality either comparable to or better than that presently produced. There are a number of approaches available to achieve this goal. One of the approaches often considered first is developing materials with hybrid vigor; i.e., progeny with characteristics better than either parent. Hybrid vigor is a phenomenon that can occur for either intra- or interspecific crosses. While growth rate is the characteristic most commonly thought of for hybrid vigor,

other characteristics such as specific gravity and form can be of equal importance. Another approach is to breed trees that require less growing space than the trees presently produced; thus, more stems and more volume can be produced per unit area. Breeding for disease and insect resistance, photosynthetic efficiency, or maximum response to intensive silvicultural practices such as fertilizing and irrigating are other approaches that can be followed. In truth, few breeding programs exist without all of these approaches woven into their basic plan. The difference in choice of approach is generally a matter of emphasis or priorities.

The factor of polyploidy is employed and given high emphasis at The Institute of Paper Chemistry. Exaggerated, genetically controlled characteristics can be obtained in some plants by changing the number of chromosome (rodlike bodies in the cell nucleus which contain the genes, the units of inheritance) sets. In aspen, the cell nucleus normally contains two sets of 19. It has been found that aspen with three sets per cell (triploids) usually have better growth and longer fibers. Triploid quaking aspen have been found occurring naturally (van Buijtenen *et al.* 1957) and triploid aspen hybrids have been produced (Benson and Einspahr 1967) artificially (fig. 1)

Suckering ability of the developed material is an important consideration in the IPC program. One of the more important benefits of aspen is its ability to regenerate and produce a fully stocked stand after harvest (fig. 2). Materials that sucker well should not only give adequate restocking but should continually improve the stand through natural selection. The stronger, faster growing clones that are more resistant to insect and disease problems and better suited to the site should dominate the stand more and more with each harvest and regeneration.

## SEED PRODUCTION

Briefly, the aspens are dioecious, and have a 1-to-1 sex ratio with the males flowering more frequently and abundantly than the females. Abnormalities such as bisexuality, perfect flowers, and late flowering have been observed. In the Lake States the flower buds apparently are initiated in May and June and are dormant through most of the winter. Flowering

begins in the early spring before leaf flush. Quaking aspen begins flowering anywhere from late March through mid-April, depending on the latitude. Bigtooth aspen, generally follows about 2 weeks behind quaking aspen in the same locality. Pollination begins about 2 weeks after the flowering, with seed fall occurring when the leaves are fully expanded (4 to 5 weeks after pollination).

The seeds are attached to hairs, facilitating seed dissemination by the wind. The seed size can be likened to coarse ground pepper, with about 7,500 seeds per gram for quaking aspen and about 10,700 seeds per gram for bigtooth aspen. Seed germination is high, but the exacting requirements for mineral soil, adequate light, and moisture greatly limit natural regeneration through seeding.

In artificial seed production a cut-branch technique is generally used. In the Lake States the procedure can be started after mid-January for quaking aspen, but should not be started before February for bigtooth aspen. The technique involves forcing flower buds on bundles of cut branches (2 to 3 feet long) to flower by putting the branch bases into a vase of ice water. The bundles are kept in the greenhouse at 65° F. with normal light (daylight). The branches are clipped and the ice water changed daily to prevent vascular plugging of the stems. In this condition the male flowers should shed pollen and the female flowers should become receptive in 7 to 11 days. The female flower buds are generally forced a week later than the males to assure pollen availability for receptive females. During the periods of pollen shed and female receptivity each bundle is kept isolated from all but one pollen source.

When the male catkins are ripe they are collected and allowed to dry at room temperature for 24 hours in paper boxes. After drying the pollen is extracted by shaking the catkins over a 100-mesh screen, which holds back the debris and allows the pollen to pass through. The pollen is put in a cotton-stoppered vial and stored at 40° F. over calcium chloride until it is to be used. When the pistils of the female flowers are brightest red or pink, depending on the species, the specified pollen is applied directly to the filament with a camel hair brush. Filaments dry up within a day if the timing is right; otherwise, a second pollination may be necessary 1 to 2 days later. After the filaments have dried up, the bundle can be washed



Figure 1. — *Pictured are triploid progeny of P. tremuloides Michx. (diploid) x P. tremula L. (tetraploid). At 13 years the trees at a 9 by 9-foot spacing averaged 51 feet in height and 6.0 inches d.b.h.*



Figure 2. — *The suckering ability of quaking aspen is illustrated in this photo. The material is 8-year-old suckers from a planting cut back at 5 years. The suckers average 15.5 feet in height, 1.1 inches d.b.h. and 4,230 stems per acre.*

with a water spray and removed from isolation until seed is shed.

Seed shed begins about 21 days after pollination. During the shedding each cross is kept isolated from the other shedding crosses. Seed and cotton are collected with a vacuum cleaner and the seeds kept refrigerated a 40° F. over calcium chloride until the seed is ready to be sown. The seed is cleaned by tumbling the cotton with air in a glass jar over soil screens (Harder 1970). If a series of screens is used, the seed can be classified to size in the same operation. Seed production varies between females and type of cross. Up to 700 seeds per catkin pollinated have been produced using this procedure although the average

production is closer to 150 to 300 seeds per catkin pollinated.

All the aspens may be artificially crossed using the above technique. In ease of handling, the females of the native and exotic species may be ranked as follows: *P. tremuloides* Michx., *P. x canescens* Sm., and *P. tremula* L. with ease; *P. alba* L. less easily; and *P. grandidentata* Michx. with great difficulty. It is most difficult to judge when *P. alba* L. is receptive because its filaments have a lighter color. It also produces fewer seeds per catkins pollinated *P. grandidentata* Michx. is more sensitive than the other species, takes slightly longer to produce seed, loses catkins easily, and produces smaller seed.

## SEEDLING PRODUCTION

At The Institute of Paper Chemistry aspens have been raised routinely from seed to plantable size (2 to 4 feet depending on the material and conditions) in a single season since 1959. Plantable seedlings also have been raised at a commercial nursery (Benson and Dubey 1972) using essentially commercial techniques. Critical steps are proper seed storage (40° F. over calcium chloride) until the hour of seeding, fumigating the seedbeds with methyl bromide, maintaining a moist seedbed the first 2 weeks after seeding, and periodic application of captan through the first 8 weeks to prevent damping-off infections. The seedlings are cut back to 1 foot and lifted in the fall when dormant, then heeled-in in a sand bed in an unheated building. The seedlings can then be taken from the sand in the spring and bundled for transport to the planting site.

## ESTABLISHMENT OF PLANTINGS

Establishment problems for aspen are similar to those described by Schreiner (1945) for poplar plantings. In old fields eliminating sod prior to planting and controlling it during the first 2 years is essential to good establishment (fig. 3). With good sod control during the first 2 years, average heights of 8 feet and more can be obtained; without it, average heights of more than 3 feet are seldom obtained. The only method demonstrated to date that gives uniformly good control of competing vegetation is mechanical cultivation. For all-around control after planting, rototilling works best; cultivation with a spring tooth, disk, or quack digger can work almost as well if cultivation is timed properly for the most effective weed kill.

A number of herbicides have been tried in both



Figure 3. — Good cultivation during the first 2 years is shown in this 4-year-old plantation. In the background are several *P. grandidentata* Michx. x *P. x canescens* Sm. individuals that are 28 feet tall. The smaller trees in the foreground are better-than-average planted bigtooth aspen, demonstrating the difficulty of establishing bigtooth.

IPC and industrial plantings but none have controlled competing vegetation consistently without hurting the aspen.

Planting in a trench (machine with scalpels) has also been tried with poor results. Aspen plantings not cultivated have become established after 5 years with 25 to 50 percent stocking. The trees in these plantings are bushy and poorly formed due to deer browsing and insect and disease attacks. The trees will eventually reach a size where cutting back will result in a reasonably well-stocked sucker stand. Following the "no cultivation" practice can only result in the first planting being a biological and fiscal disaster with the newly formed sucker stand established at the cost of a noncommercial or minimum production harvest. The cost of mechanical cultivation at first seems too high to be profitable; however, with imagination, successful ways such as spacing adjustment or intercropping can be found to reduce the cost to reasonable levels. On light soils deep-planting aspen from 4 to 12 inches above the root collar has resulted in no adverse establishment effects and in dry years has benefited survival and growth.

Aspen plantings have been made in clearcut northern hardwood stands. Growth of the aspen in these areas was observed, during the first 5 years, to be better than uncultivated aspen planted in plowed fields but considerably poorer than well-cultivated aspen plantations. Aspen also grew better than the hardwood regeneration on the cutover area. When planted in areas that developed into aspen sucker stands, the planted aspen tended to be codominant or suppressed, depending on the available growing space. This was better growth than anticipated under these conditions, as planted aspen have a much lower food reserve and less root system available than suckers growing on the root systems of harvested mature trees. The critical factors for establishment of aspen on either old fields or clearcut areas are pressures of deer browsing and herbaceous competition.

### PROMISING MATERIALS

It is ironic that people tend to object to interracial marriages of their own kind but generally think of interspecific hybridization as a method to produce the most improvement in plant or animal breeding. The truth is that discretion is needed in either situation.

### Intraspecific Hybrids

In the IPC program about two-thirds of the aspen breeding work concerns intraspecific (within species) crossing. A large portion of these crosses are made to evaluate selected trees as parents, evaluating both their breeding performance and the performance of their progeny. Good combinations can be repeated, superior individuals within a progeny group can be used and evaluated as parents, and parents with proven ability to produce good offspring are used in further crossing work, either intraspecific or interspecific.

Of the intraspecific crosses the bigtooth aspen are the least impressive. This is primarily due to the difficulty of establishing the material in plantings (fig. 3). They prefer sandier soils and have slow early growth, 2 feet per year for the better materials under good cultivation. No crosses of bigtooth aspen have yet been found that can be recommended for planting.

Quaking aspen crosses prefer fresher, richer soils of medium texture and respond well to cultivation, the better materials growing 3 to 3½ feet per year. Several promising quaking aspen crosses have been developed. While the progeny of these crosses do not have the growth rate of the best interspecific hybrids, they offer somewhat more uniform growth and establishment, have better suckering ability than any of the materials tested, and, being native, offer more predictable estimates of risk due to damage by insects, disease, or other factors. The potential available using quaking aspen intraspecific crosses has been undersold; considerable gains can be made using improved materials of this kind.

Several exotic intraspecific crosses have been made, primarily to broaden the base of breeding stock available locally. None of the exotic species are considered as possible answers for improved progeny groups, although certain individuals may rate consideration for clonal propagation. *P. alba* L. is too poorly formed, being generally branchy with crooked boles. *P. x canescens* Sm. is too variable, perhaps due to its supposed origin as a natural interspecific hybrid. *P. tremula* L. generally has shown less vigor than the native quaking aspen and is not considered desirable for this reason.

## Bigtooth Aspen Interspecific Hybrids

Perhaps the best known interspecific aspen hybrid in the Lake States area is *P. grandidentata* Michx. x *P. alba* L., due to the publicity given Iowa hybrids (McComb and Hanson 1954). Several naturally occurring hybrids of this type have been found and many are being tested clonally with hybrids from controlled crosses. Twenty-six crosses of this type have been made at The Institute of Paper Chemistry and 12 were successfully outplanted. Seed production is low for this type of cross. Their growth is superior to native aspen on dry, sandy soils (fig. 4), but their vigor is maximized on fertile, fresh soils. The wood quality of these materials is similar to native aspen

but the suckering ability is not as good. While branchiness is excessive and bole straightness is generally poor for this material, it can be accepted due to the gains in vigor. A number of plantings have been made in the United States and Canada with vigor obvious in most areas. A dieback of this material was noted by Heimburger (1968) in the Canadian plantings. Sunscald has been the most prevalent malady in the IPC plantings, but so far has not been great enough to discredit the material. The hypoxylon canker, *Hypoxylon pruinaum*, has been occasionally observed on trees of this material. While deer will browse this hybrid, they seem to prefer native aspens. Another plus for this type of hybrid is that dormant cuttings can be rooted with an average success of 35 percent.



Figure 4.—Pictured is a 10-year-old planting of *P. alba* L. x *P. grandidentata* Michx. progeny growing at a 9 by 9-foot spacing on a dry, sandy soil. The planting averages 41.5 feet in height and 5.3 inches d.b.h.

*P. grandidentata* x *P. x canescens* Sm. is an interspecies hybrid, not as well known as "alba x bigtooth," that has exceptional promise (fig. 3). Forty-eight crosses of this type have been made in the IPC program and 33 successfully outplanted. This material exhibits better form than the "alba x bigtooth" hybrids and seems to have similar vigor. Trees growing on dry, sandy soils have reached 28 feet in 4 years. Suckering ability is still unknown, but it is expected to be similar to that of the "alba x bigtooth." No major insect or disease problems have been observed on this material as yet.

Some interspecific crosses have been made between bigtooth aspen and some Asiatic aspen. In the case of the combination with *P. sieboldii* Miq., the crosses did not produce seeds successfully. Crosses for this type of hybrid were only made in one season and have not been repeated since, so it has not been well tested. Three crosses with *P. davidiana* Dode were made and two were successful and outplanted. While these crosses grew well, one exhibited an extreme susceptibility to hypoxylon canker. The above-mentioned Asiatic aspen are supposedly linked to European trembling aspen, *P. tremula* L.

### Quaking Aspen Interspecific Hybrids

Several interspecific hybrids using quaking aspen as one of the parents have been produced. They generally grow best on sites similar to those utilized best by quaking aspen. *P. tremuloides* Michx. *P. tremula* L. is one combination that has done well in Europe (International Poplar Commission: FAO International 1958), Canada (Zufa 1969), and in IPC plantings. This material grows slightly faster and is more robust than quaking aspen growing on the same site. The suckering ability and wood quality of these materials is not well tested under the IPC program yet, but there is evidence that both qualities are at least as good as in the native quaking aspen.

Crosses of *P. tremuloides* Michx. with the two Asiatic aspen have been made and tested. Pollen from *P. sieboldii* Miq. was imported and used with quaking aspen. Good results were obtained in the breeding work and nursery production with this cross, but the field plantings were poor. The initial growth and survival was good, but by the end of the second season the material began to show an extreme susceptibility to *Agilus hornii*, a root-boring *Agilus*,

and by the sixth year 63 percent of the trees survived and were stunted. Hypoxylon cankers were observed on some of the survivors. This cross was not repeated so it cannot be said whether this was typical behavior. Four crosses have been made on quaking aspen with pollen from *P. davidiana* Dode. Two of the crosses resulted in superior outplantings and two failed as outplantings. The failures were due to selective infestation by *Agilus hornii*. In this case it can be assumed the particular parent combination was a factor. The two successful crosses were outplanted on more than one site and have shown impressive field performance — impressive enough to encourage their future use and to investigate this cross more thoroughly.

One triploid hybrid, *P. tremuloides* Michx. x *P. tremula* L., 4n, has been very successful (fig. 1). The material grows similarly to quaking aspen through the first few years and then proceeds at a faster rate, producing taller, more robust trees. The material has shown specific gravities and fiber lengths greater than those of native quaking aspen (Einspahr *et al.* 1968). It also has excellent suckering ability, perhaps better than quaking aspen. Tests are presently under way to distinguish the gains due to triploidy from those due to interspecific hybridizations.

Twenty-five crosses between *P. tremuloides* Michx. and *P. x canescens* Sm. have been made with 17 successfully outplanted. This material is characterized by high vigor, ability to grow on several sites, and some drought resistance. Because most of the outplantings of this material are young, characteristics of larger trees are not certain. It is suspected these materials will tend toward branchiness and poor bole form.

Quaking aspen has also been crossed with *P. alba* L., but this cross, while vigorous, is generally considered poorer than the "alba x bigtooth" because of its greater branchiness and poorer bole form.

The above-mentioned aspen hybrid evaluations are primarily confined to IPC plantings. A number of other types of crosses — those with three species combined, back crosses, and crosses with species in other *Populus* sections not as closely related to the aspen — have been made but are generally not exceptional in vigor or form. As more of these types of crosses are tried, better results may be obtained. It should also be restated that for the previously mentioned aspen

hybrids parent combinations are very important and that superior hybrid progeny groups or single clones may be developed from any of the mentioned hybrids. The heterogeneity of aspen allows a wide range of results in aspen breeding work, ranging from frustrating ones to those with considerable promise.

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# REGENERATION: BIOTIC AND SILVICULTURAL FACTORS

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**ABSTRACT.** — Vegetative regeneration by suckering can be successful in harvested aspen stands only if competition from residual vegetation is largely eliminated. Mechanized timber harvest can best create the site conditions necessary for successful and complete aspen regeneration. Prescribed burning or release by aerial spraying of herbicides also are effective tools.

The North American aspens, trembling and bigtooth, can be regenerated by seeding, stem and root cuttings, and even from tissue cultures (Winton 1968) but by far the least expensive, most practical and reliable method is vegetative regeneration by root sprouts or suckers.

## VEGETATIVE REGENERATION AND THE CLONAL CONCEPT

The spreading cord-like lateral roots of aspen usually produce a great number of suckers when the parent tree is killed and the forest floor warmed by insolation (Farmer 1962, Maini and Horton 1966a). Following harvest of a well-stocked aspen stand, as many as 60,000 suckers may be regenerated per acre. All suckers growing from the roots of the same parent belong to a genetically distinct group or clone, and each stand consists of several clones. Excavation of one trembling aspen stand showed that about 70 percent of the suckers were located on seven different root systems with as many as 15 suckers on the same root system (Barnes 1966). Repeated destruction of a stand at intervals of several years will result in enlargement of some clones and intermingling according to their ability to compete with one another (Barnes 1966).

Most suckers arise from roots averaging about  $\frac{1}{2}$  inch in diameter which, for trembling aspen, lie within an inch of the soil surface, and for bigtooth aspen, within 3 inches (Sandberg and Schneider 1953, Farmer 1962). Suckers may originate more than 80 feet from the parent stump (Graham *et al.* 1963).

Drawing on the parent roots for nutrition, aspen suckers develop rapidly and dominants commonly grow 4 to 5 feet their first year. Young suckers soon produce adventitious roots, and in many cases develop independently if the parent root system decays (Sandberg and Schneider 1953). However, functional root connections occur between aspens up to 65 years of age (Quaite 1953, De Byle 1964, Maini 1968). The distal parent root thickens with time indicating its greater contribution to sucker growth than the proximal root which remains relatively unchanged (Day 1944). It is not until about age 25 when the adventitious roots of bigtooth aspen become more important than the parent root to sucker growth (Zahner and De Byle 1965).

## GENETIC VARIABILITY OF CLONES

Aspen clones vary considerably in genetic traits such as leaf morphology and seasonal coloring, stem form, branching habit, growth rates, bark characteristics, sex, and phenology (Barnes 1966). Stems of recognizable single clones may cover from 0.05 to 35 acres (Blake 1964, Barnes 1966). The clone concept is of great importance in interpreting research results for aspen management since genetic variation also greatly affects suckering capacity and may mask variation in suckering due to site index or stand age, for example. Six clones of bigtooth aspen varied sevenfold in numbers of suckers produced after clearcutting (Garrett and Zahner 1964). Other bigtooth and trembling aspen clones varied fourfold in sucker numbers (Farmer 1962) and even up to twentyfold depending on temperature regime (Maini 1967).

Variability in initial growth and survival of suckers may be due to clonal variability of root carbohydrates (Tew 1970, Schier and Johnston 1971).

Variability in suckering under different ecological conditions could be an important tool in management efforts to increase the area of desirable clones. For example, partial cutting may leave a site cooler than clearcutting would, thus favoring suckering of one clone over another. After regeneration is achieved, a clearcut of the remaining stand would allow sucker development of the preferred clone.

## STAND FACTORS INFLUENCING SUCKERING

Suckering generally increases as the density of the parent aspen stand harvested increases, whether density is expressed in number of trees, basal area, or volume (Stoeckeler and Macon 1956, Graham *et al.* 1963). Some trembling aspen stands have regenerated satisfactorily in northern Minnesota where stocking was only 20 square feet of basal area per acre.<sup>1</sup>

Sucker stocking generally decreases as density of the residual overstory increases. Aspen suckers are intolerant of shade and require full sunlight to develop. Stoeckeler and Macon (1956) found sucker numbers increased twentyfold when the overstory decreased from 100 square feet basal area per acre to 0. Competition from understory shrubs (Stoeckeler and Macon 1956), bracken fern (Maini and Horton 1966b) and the overstory reduces height growth and survival of suckers (Zehngraff 1947, Farmer 1963). First year dry weight increment of trembling aspen suckers may decrease by a factor of three with increasing basal area density of the residual overstory.<sup>1</sup>

Evidence on the effect of age on the ability of clearcut aspen to sucker is conflicting. Suckering increased up to age 70 in one Minnesota study (Kittredge and Gevorkiantz 1929) although in another study age had no effect (Sandberg and Schneider 1953). Suckers reached maximum numbers for big-tooth aspen at age 40, and for trembling aspen at age 35 in the lower peninsula of Michigan (Graham *et al.* 1963). In Canada, suckering was similar in root cutting from aspen 20 to 150 years of age (Maini 1968). Wisconsin stands averaged 1,852, 2,011, and 2,807

suckers per acre when cut at age 30, 40, and 50 respectively (Stoeckeler and Macon 1956).

Very young aspen stands may regenerate well when clearcut. In northern Minnesota, trembling aspen stands 2, 4, and 8 years of age averaged 30,000, 35,000, and 41,000 suckers per acre respectively the first year after clearcutting.<sup>2</sup>

Aspen suckering in Wisconsin stands increased as site index increased (Stoeckeler and Macon 1956) but in Minnesota stands, site quality did not affect suckering (Sandberg and Schneider 1953). Sound conclusions are difficult to make since better sites usually yield a higher stocking of aspen, an important variable in sucker production. Also height growth of genetically superior clones on poor site may exceed that of inferior clones on a better site (Zahner and Crawford 1963). Thus genetic variability may account for apparent differences in site quality as well as sucker production.

## SILVICULTURAL PRACTICES FAVORING SUCKERING

The only factor the forest manager can manipulate to regenerate harvested aspen stands is the degree of overstory and understory competition remaining. The other factors affecting sucker regeneration — aspen stocking, stand age, clonal variability, and site — are fixed for a given mature stand. But the forest manager can take steps to ensure the next stand is well stocked with aspen. The basic requirement is to control competition from the remaining vegetation using one or more of the following techniques.

### Full-Tree or Tree-Length Harvesting

Tree-length harvesting systems probably offer the greatest potential for properly regenerating aspen stands, and could eliminate the need for any further treatment to encourage suckering. Nearly all of the overstory and understory shrubs were eliminated in one study when fellers and skidders were told not to favor residual trees or advanced regeneration during their mechanized harvesting operation (Zasada and Tappeiner 1969). Excellent sucker regeneration was achieved and the new stand should be virtually 100 percent stocked with aspen at maturity.

<sup>1</sup> Unpublished information by the author.

<sup>2</sup> *Ibid.*

## Felling or Girdling Residuals

Residuals may be felled or girdled but this can be the most expensive method of site clearing, and costs will soar in mixed stands with many unmerchantable trees. Saskatchewan and Manitoba now require complete clearcuts in aspen (Jarvis 1968) and many National Forests require all trees over 2 inches d.b.h. to be felled.

## Chemical Control of Residuals

Individual residual trees other than aspen and larger than 3 or 4 inches d.b.h. may be killed by cut-bark treatments. Dilute herbicides can be applied to the sapwood by a tree injector.<sup>3</sup> The incisions should extend one-fourth to one-half inch into the sapwood as close to the base of the tree as practical (Arend and Roe 1961). Tests with new chemicals containing picloram (4-amino-3,5,6-trichloropicolinic acid) have given good results on species that generally have been resistant to herbicides (Brinkman 1970). Tree injection treatments cannot be used on aspen because the chemicals may be transported through the connecting root system and thus prevent suckering (Quaite 1953).

Experimental aerial applications of 3 pounds acid equivalent per acre of 2,4-D or 2,4-D/2,4,5-T mixture in early August generally have been successful in reducing residual overstories (Perala 1971). Paper birch and red oak were readily killed but red maple and basswood were highly resistant. Aspen suckers already established were killed to the ground line but the unaffected parent roots produced an abundance of suckers the following year. Chemical treatments to remove competition should be made within the first two growing seasons after logging to avoid partial kill of older suckers which can lead to possible stem distortions.

## Ground Scarification

Scarification improves sucker initiation and survival by reducing the understory, litter, and duff, and exposing the forest floor to solar radiation. Undisturbed litter may foster a high cutworm population which can in some cases eliminate the succulent

emerging suckers (Graham *et al.* 1963). Leveling the understory also gives aspen suckers an excellent chance of overtopping the slower growing shrub regeneration. Sufficient scarification can usually be achieved in harvesting if skidding covers much of the cutting area. Scarification may be poor after winter logging in deep snow.

If harvesting fails to scarify an area sufficiently, other means such as shearing can be used, but only at great expense. Sheared aspen sites invariably result in dense aspen suckering. Discing also has initially increased sucker stocking (Zehngraft 1946b, Zillgitt 1951), but several field reports of poor survival and height growth suggest that this method should not be recommended.

## Prescribed Burning

Many studies show that burning increases the number of suckers (Shirley 1931, 1932; Horton and Hopkins 1965; Buckman and Blankenship 1965; Maini and Horton 1966b; Tucker and Jarvis 1967). Perala<sup>4</sup> found that dormant season burning increased aspen suckers from a preburn number of 17,000 stems to 24,000 per acre. More important, the fire killed 75 percent of the standing residual hardwoods and cull aspen and reduced their basal area from 30 to 7 square feet per acre.

Several important conditions are necessary for successful prescribed burns in aspen: uniform distribution of fuels for complete burn coverage; suitable burning conditions; and well-cured fuels. Aspen slash may require up to one year curing before it will sustain a fire hot enough to kill standing residuals.

The recommended weather conditions and minimum burning indexes (Nelson 1964) for a successful prescribed burn in aspen are:

Air temperature	> 65° F.
Relative humidity	< 35 percent
Buildup index	> 30
Timber spread index	> 25
Wind	6-12 m.p.h.
Number of days with less than 0.1 inch rain	> 5

<sup>3</sup> See page 103.

<sup>4</sup> Unpublished manuscript by the author.

Burning in the autumn is preferred over spring burning because of greater availability of standing fine fuels to carry the fire.

### Season of Harvest

If prescribed burning or mechanized harvesting is not carried out, then the season of aspen harvest may affect sucker production. Although evidence is conflicting, it is probably desirable to harvest aspen during the dormant season especially in areas where brush or bracken fern would compete with regeneration if it were harvested during the growing season (Stoeckeler and Macon 1956, Graham *et al.* 1963).

Zehngraff (1946a) reported less suckering in spring- and summer-logged northern Minnesota aspen stands. Suckers produced later in the season were short and succulent, susceptible to frost, and less able to compete with brush. In Wisconsin, sucker numbers following late summer harvesting were about three-fourths of that following dormant season harvesting (Stoeckeler and Macon 1956). However, studies in Michigan and Minnesota showed that season of logging had little effect on the number of suckers present after two growing seasons (Sandberg and Schneider 1953, Graham *et al.* 1963).

Stoeckeler (1947) felt reduction in suckering may be linked with low levels of carbohydrate reserves in the roots during active leaf development in the spring and early summer. Tew (1970) found carbohydrate reserves varied with the season. However, the length of the period of sucker production rather than the number of suckers produced varied with the carbohydrate reserves. The variability in reports on aspen suckering according to season of harvest is probably tied closely to other variables such as genetic variation and the amount of understory and overstory competition left after logging.

### HOW MANY SUCKERS ARE ENOUGH?

Past studies suggest 6,000 suckers per acre are needed for a minimum initial stocking (Graham *et al.* 1963). Stoeckeler and Macon (1956) show that 6,000 per acre would result in 90 percent milacre stocking and 9,000 per acre virtually assures 100 percent stocking. But uniform distribution is as important as density for obtaining good aspen regeneration. Sorenson (1968) concluded that an initial 1,000

well-spaced suckers per acre would yield as great a volume in crop trees at age 15 as a stand having an initial density of 10,000 stems per acre.

Under conditions of complete overstory removal and good scarification, more than the minimum 6,000 suckers are usually obtained to fully utilize the site and obtain maximum production of wood or fiber. High density aspen stands undergo less attack by hypoxylon cankers (Anderson and Anderson 1968) and are less susceptible to damage by poplar twig borers (Myers 1967). However, in Michigan, dense stands of over 35 thousand suckers per acre sometimes suffer excessive mortality, leaving too scattered a stand for best development (Graham *et al.* 1963). Initial high sucker densities obtained in Minnesota (up to 60,000 per acre) are reduced rapidly in numbers through natural mortality yet total productivity remains higher than in less dense stands.<sup>5</sup>

### SUMMARY OF TREATMENTS FOR SUCCESSFUL REGENERATION

Complete removal of overstory and scarification to minimize understory competition are necessary for aspen suckering. Full-tree or tree-length harvesting systems when properly administered can meet these requirements without further treatment. Where short-wood systems are used, all unmerchantable trees should be removed. Residuals can be felled or chemically treated following a timber sale if only a few remain. If many are left it will be more economical to burn, especially if the residuals are conifers or are herbicide resistant. Prescribed burning is also recommended to reduce understory competition. If the overstory consists of species with low resistance to herbicides, aerial spraying may be a suitable alternative. Mechanical treatments, such as shearing, are recommended only as a last resort due to their expense. A minimum initial stocking of 6,000 suckers per acre is needed for good regeneration.

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<sup>5</sup> Unpublished manuscript by the author.

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## PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key — out of the reach of children and animals — and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.



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U.S. DEPARTMENT OF AGRICULTURE

# SIMULATION OF GROWTH:

## A New Approach to Yield Forecasting

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**ABSTRACT.**—For increased efficiency in timber growing, the forest manager needs to be able to forecast the outcome of alternative silvicultural strategies and select the optimum one for any given set of management objectives. There are many potential stand condition and treatment combinations. A general and flexible approach is outlined for yield forecasting that could eventually provide the needed answers. This “stand model” simulates periodic height and d.b.h. increment of every tree on a sample plot, from starting age to harvest, and calculates stand characteristics simply by summing tree data for a unit area. Some potential uses of the model in aspen management are given and development work in progress is outlined.

The usual way of forecasting growth and yield of forest stands is from yield tables or functions. Smoothed trends of yield for a given species—expressed in terms of age, site index and possibly basal area density and average d.b.h.—are based on stand data from sample plot measurements. Schlaegel's (1971) yield tables for aspen is one example.

These methods of forecasting forest yield have been widely accepted and used by forest managers. Current rapid advances in utilization and increasing demand for wood fibre will require intensification of forestry practices as well as improvements in management planning and analysis. For the latter, it will be necessary to forecast yield for a number of alternative stand conditions and treatments and to select the optimum combination for a set of management objectives.

Yield tables are not suited for this purpose because their use in prediction is limited to stand conditions similar to those of the original sample. A more general approach is needed to predict yield. Its main objective should be to make long-term forecasts for treatment comparisons rather than just to provide short-term predictions for specific, undisturbed stands.

### NEEDED: A FLEXIBLE METHOD,

### A SIMULATION MODEL

Although further improvements are possible in the yield table method of forecasting, one cannot overcome the main limitation of the method: its use is restricted to the specific conditions of the data base, beyond which extrapolations are fraught with danger. This limitation of yield tables arises from their reliance solely on stand parameters. The use of stand averages in this way tends to conceal causal relations that might provide the basis for major improvements in forecasting methods. Processes of stand growth and development should be studied and evaluated on an individual tree basis, because that is the seat of such processes; whereas stand growth and yield may simply be looked at as the sum of individual tree performances on a unit area.

Although much tree growth information has been collected in the past, there was no technique to synthesize the data into models that would provide meaningful estimates of stand growth and yield.

The advent of large, high-speed computers made

the development of these simulation models possible. The computer has three main functions: (1) it provides a structural frame-work—in form of a stored program—for the forest system, including the descriptions of all the important interactions that affect tree growth and mortality; (2) it stores relevant information on *every* tree (e.g., height, diameter, spatial coordinates); and (3) it evaluates (computes) in quantitative terms the effects of all the requisite interactions.

To build a stand growth model, one begins with the identification of the most important components of tree growth. These components in the aspen model are:

Soil and climate (expressed by height growth of dominants).

Species characteristics (tolerance, growth habits, clonal characteristics).

Age.

Intertree competition (stocking, stand density, and structure).

Next, all the components require quantitative description. Because of the complexity of the forest system, and our limited knowledge of it, simplifications are usually necessary to describe the relationships. The more important of these simplifications are called assumptions. They should be stated clearly in a model and their limitations recognized. Increasing the number of assumptions usually weakens the model.

These components then have to be reassembled (i.e., interfaced) and translated into a suitable computer language. Flow charts are useful to help visualize interrelations (fig. 1). A stand model can be developed to practically any degree of refinement, depending on the degree of complexity of the stand and the availability of basic data, time, and money. In the aspen model, for example, clonal structure of the stand may be included directly by assigning a clone identification number to each tree. In this model, however, clonal effects are considered only in terms of tree-growth differences.

## A STAND GROWTH MODEL

Simulation of aspen stand growth in this model is based on height-growth trends of dominant trees.

Using height increment in this way is particularly suitable for simulating aspen growth, because aspen is an intolerant species that readily expresses dominance even in dense stands. Results available from a number of aspen growth (reviewed by Bella)<sup>1</sup> show that height growth of the largest trees is quite stable and is not affected by competition. Thus height growth of these trees in a stand can be predicted accurately. The height-growth regression necessary for simulation can usually be derived from site index curves.

The same kind of relation seems to hold for diameter growth of the largest trees in vigorous young aspen stands, at least up to 15 years of age (Sorensen 1968). These relations have to be defined in stand growth simulations as they indicate limits of competition effects on tree growth.

The model generates potential height increment for each individual tree during a simulation run. These increment values include, in addition to the mean trend value for a given clone and period, a certain amount of random variation. Potential height increment is reduced according to each tree's competitive position, or index. Evaluating this index of competition is the most crucial part of the model. Background work for this is presented by Bella (1971).

Potential diameter increment is estimated from potential height increment using an appropriate regression derived from open-growing aspen tree data. This potential increment is reduced according to the tree's competitive status using a numerically derived relationship.

One of the most difficult problems in forecasting growth and yield of forest stands is the meaningful prediction of mortality. Mortality both from suppression and from other causes, can be handled readily in the model. Basic data for model building can be obtained from permanent sample plot records that include a frequency distribution of dead trees by size and final increment classes at different ages. Criterion of death in the model is defined so that simulated results of mortality distributions of dead trees conform to what is found in actual stands. In the aspen model, suppression mortality is assumed to be directly

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<sup>1</sup> Bella, Imre E. *Simulation of growth, yield and management of aspen*. Univ. Br. Col., Fac. For., Unpublished Ph.D. Dissert. 190 p. 1970.

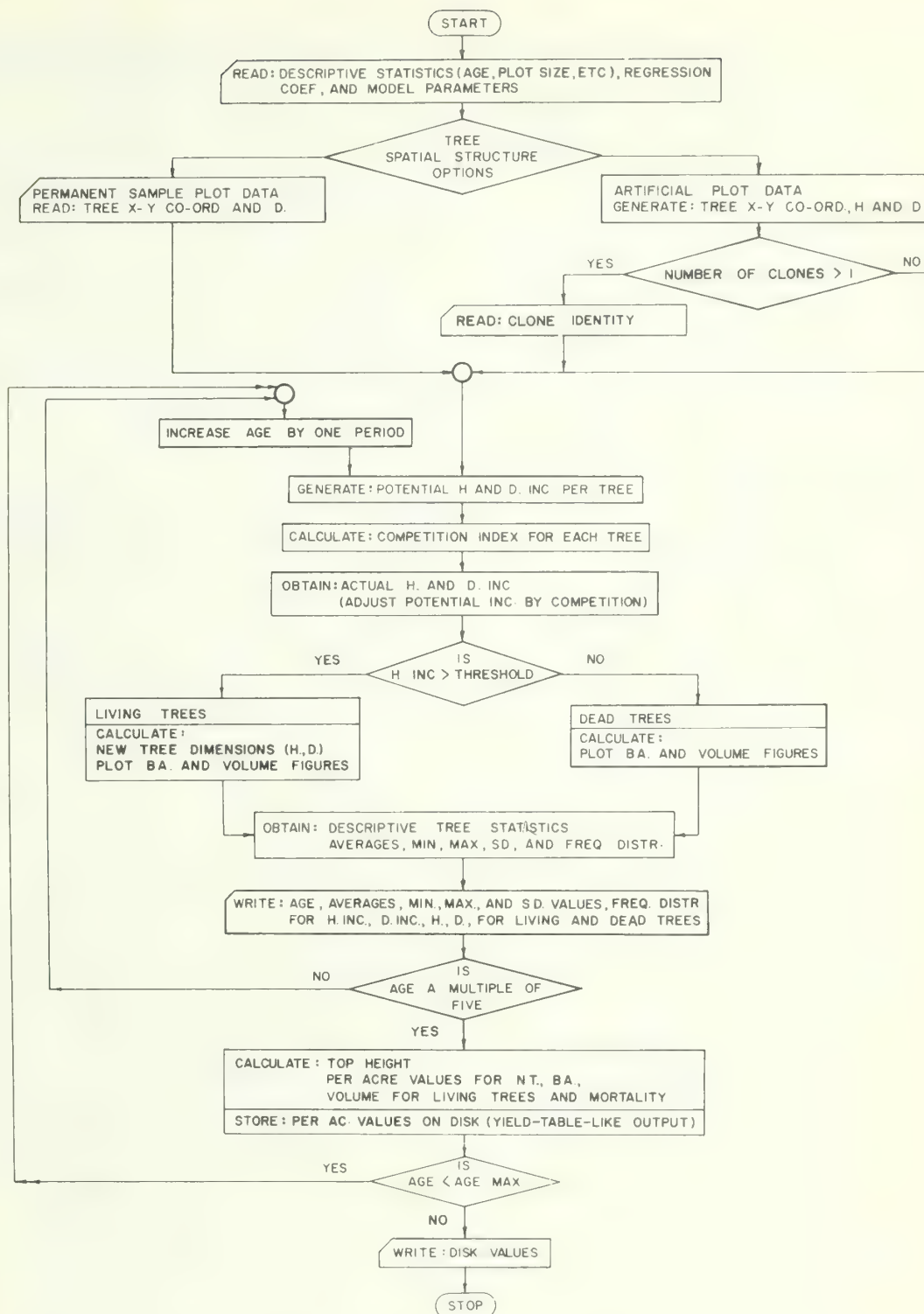


Figure 1. — General flow diagram of the aspen stand growth model (where BA. = Basal Area; D. = Diameter; FREQ. DISTR. = Frequency Distribution; H. = Height; INC. = Increment; NT. = Number of Trees; SD. = Standard Deviation). Notations and symbols are similar to those used in FORTRAN programming.

related to the trees' competitive status and inversely to current increment—including a certain amount of random variation. Simply, trees most likely to die are the ones with high competition index and slow growth.

It was relatively easy to work out in the aspen model how to simulate tree growth at the two extremes of the competition spectrum; i.e., for the largest dominants and for the small, suppressed trees. The difficult part was the simulation of tree growth between the extremes. Some of the relationships between tree growth and competition were derived numerically. That is, algebraic expressions were developed by trial and error to conform to current knowledge of competition effects.

### TESTING THE MODEL

Each component is analyzed and tested during model building, using experimental data as much as possible. Standard statistical techniques, however, are not suitable to validate the complete model because of its "loose" nature due to the interfacing, presence

of random components, and the incorporation of different assumptions through model coefficients. One of the better ways of validation is to compare actual yield from a permanent sample plot with simulated yield of the hypothetical stand. Initial stand conditions would have to be identical. Appropriate yield table statistics also provide some useful comparisons.

Although yield tables are usually tested for conditions in which they are to be used, a similar test of the model would neither be practical nor necessary. Because a simulation model is realistic, it may be considered sufficient to validate it with only certain benchmark values.

The aspen model has been tried for simulating the growth of aspen only in undisturbed, natural stands of average, or below average density. For greater ease of calibration, the trees in the hypothetical stand were assumed to belong to the same clone. After the various model coefficients were refined, simulated stand statistics (table 1) showed good similarity with comparable permanent sample plot data or with appropriate yield table values (fig. 2).

Table 1.—*Summaries for growth simulation of aspen stand for above-average site class in Saskatchewan (in English units per acre, and in metric units per hectare)*

Age in years	Trees				Average d.b.h.		Basal area		Volume yield		Volume		Gross volume
	Living	Over	Dead	Total	Over	Total	Over	Total	Over	Total	Over	Dead	
	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	4 in.	trees	yield
	Ft.	No.	No.	No.	In.	In.	Sq.ft.	Sq.ft.	Cu.ft.	Cu.ft.	Cu.ft.	Cu.ft.	
14	28.4	4,000	0	0	1.6	--	60	0	577	0	0	0	577
19	34.3	3,420	20	670	2.2	3.8	88	2	1,037	13	43	80	1,080
24	39.8	2,930	150	490	2.7	4.1	115	14	1,593	147	80	1,715	
29	44.7	2,490	520	440	3.2	4.2	135	49	2,111	557	132	2,365	
34	49.2	2,010	850	480	3.6	4.3	144	87	2,502	1,106	255	3,011	
39	53.2	1,690	1,080	320	4.1	4.5	154	121	2,914	1,734	245	3,668	
44	56.8	1,340	1,060	350	4.6	4.8	151	136	3,099	2,186	381	4,234	
49	60.0	1,040	950	300	5.0	5.2	144	139	3,159	2,480	434	4,729	
	Meters	No.	No.	No.	Cm.	Cm.	Sq.m.	Sq.m.	Cu.m.	Cu.m.	Cu.m.	Cu.m.	
14	8.6	10,107	--	0	4.1	--	13.8	--	40.37	--	.00	40.37	
19	10.4	8,451	--	1,656	5.6	--	20.2	--	72.56	--	3.01	75.57	
24	12.1	7,240	--	1,211	6.8	--	26.4	--	111.47	--	5.60	120.00	
29	13.6	6,153	--	1,087	8.1	--	31.0	--	147.71	--	9.24	165.48	
34	15.0	4,967	--	1,186	9.1	--	33.0	--	175.07	--	17.84	210.69	
39	16.2	4,176	--	791	10.4	--	35.4	--	203.90	--	17.14	256.66	
44	17.3	3,311	--	865	11.7	--	34.7	--	216.84	--	26.66	296.26	
49	18.3	2,570	--	741	12.7	--	33.0	--	221.04	--	30.37	330.90	

## POSSIBLE USES OF THE MODEL IN MANAGEMENT

A most obvious operational use of this model is that of a very general and flexible yield table. Detailed size data are available on every tree during a simulation run, thus stand table information can readily be printed. Stem volume estimates can be provided in any desired standard, and to specified limits of merchantability. Similar estimates may be obtained for tree weight. Most of the tree volume and weight equations are already available from earlier studies, and new ones can easily be derived.

While earlier methods of growth and yield predictions are not suited to extrapolation, an important use of this model would be to forecast yield for stand conditions on which no historical data exists. For example, stand development and yield after logging

probably will differ in aspen sucker stands from yields in stands originating after wildfires. Most of the aspen growth data now available are from stands of the latter kind, although the manager also needs to forecast yield for cutover areas.

The effect of various density control treatments, their timing and intensity, on subsequent growth and yield may be evaluated by simulation. The feasibility of new treatment techniques could be studied and answers provided without having to wait decades for experiments to mature. A problem that deserves attention is the evaluation of the effect of mechanical strip thinning on growth and yield in young aspen stands. Recent operational trials in young pine stands in Manitoba showed this kind of thinning to be an effective (in terms of growth response and lack of serious damage due to treatment) and inexpensive method of density control.

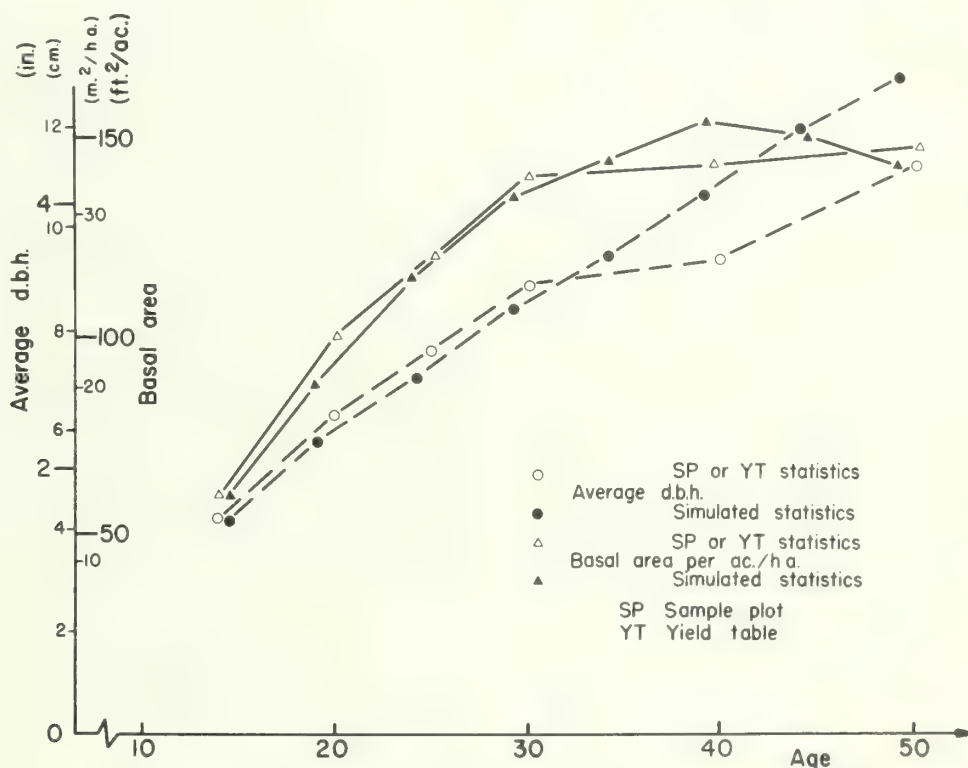


Figure 2. — Average diameter and basal area per acre trends from a permanent sample plot (up to age 30 years) and from yield tables (over 30 years, Site Index 75, MacLeod, W. K. *Yield and volume tables for aspen in central and northern Alberta. Univ. Brit. Col., Fac. For., Unpublished M.F. thesis, 66 p. 1952*), and similar trends from aspen stand growth simulation for above average sites in Saskatchewan.

If selection thinning is contemplated in aspen stands, the model may be used to evaluate the increase in yield by favoring trees in a fast-growing clone and cutting trees from poorer ones. Information on differences in tree growth from clonal effects could be taken from various clone studies, or the range in tree growth estimated from even limited data. Using the model, this tree growth information could then be translated into stand growth and yield statistics. Similar use could be made of tree growth information from tree breeding studies.

As demands for wood fibre increase, forest fertilization becomes a more practical method of increasing yield. Information will be needed on growth responses over a range of site and stand density conditions to carry out effective fertilization programs. Some basic information on tree growth and stand growth responses from pilot fertilizer trials will be required to establish some reference points or benchmarks. Then yield predictions for a range of treatments could be made with the model.

The model would also help to evaluate the relative importance of certain components and factors affecting tree and stand growth. This is done by manipulating parameters and coefficients in the model and observing the effect of these changes on growth and yield through simulation. This "sensitivity analysis" provides useful information for planning silvicultural treatments, because it enables the manager to concentrate his effort on responsive factors. For instance, if tree growth was found to be highly dependent on competitive status and relative tree size but not very dependent on spatial distribution of the trees, then thinning should concentrate on favoring the most vigorous trees, without much concern about creating some irregularity in stem distribution.

## WORK IN PROGRESS

Although simulation runs with the aspen model showed promise, they also indicated the need for further refinement and testing before the approach could be put to full practical use as a management tool. In the interim, the model should facilitate improvement in understanding tree and stand growth relations. For example, experimental simulation runs with the aspen model showed that in dense, fully stocked stands, artificial lowering of the diameter

increment of the largest trees gave rise to higher stand volume yield—a rather unexpected situation. Apparently, greater uniformity in tree sizes and the lack of less efficient "wolf" trees, resulted in a reduction of competition effects among medium size trees and an increase in their growth.

Current work is being concentrated on further testing and refining the intertree competition submodel. The effect of age and site on tree growth-competition relations has to be studied at different stand densities. Long-term permanent sample plot data with tree maps—from establishment to maturity—are needed for aspen and also for other species. In this way, effects that are species-dependent can be evaluated, a prerequisite for a better understanding of intertree competition and for its generalized description. These studies form the basis for expanding the scope of these models, perhaps to include the simulation of growth of mixed stands.

Research is needed to find out how crowding and competition in very young stands affect tree growth in later years. There is some evidence to suggest that the growth of the biggest trees (both in height and d.b.h.) in young, vigorous stands is not affected by competition (Sorensen 1968). We need to know, over a practical range of stand density levels, to what age and under what site conditions this relation may apply. We need to know how smaller trees in the stand are affected, and about their future development. Most studies show, in stands over 15-20 years of age, that if aspen grows under dense stand conditions over a prolonged period of time, the trees lose their ability to take full advantage of a sudden increase in available growing space.

This kind of information is necessary to strengthen the aspen model.

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# GROWTH AND YIELD OF MANAGED STANDS

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**ABSTRACT.** Merchantable aspen production can be increased by thinning between the ages of 10 and 30 years. Early cleaning is recommended to remove competing hardwoods. Generally, thinning should leave: 750 to 900 trees per acre at 10 to 15 years of age; 200 to 400 trees per acre at age 20 years; or about 275 trees per acre at 30 years. Thinning past age 30 is not recommended. Cordwood yields of managed stands are shown by site, age, and stand density.

Aspen stands managed for timber production will be essentially pure and they may need one or more thinnings. Management objectives may vary depending on the size of trees to be grown. Specific questions a forest manager might ask are: Should aspen stands be thinned? If so, when and how should they be thinned? To what density should they be thinned? To answer these questions, a careful examination must be made of the site quality and stand age, composition, vigor, and stocking.

## SITE

Site index is an accepted measure of aspen site productivity and is estimated from the age-height relationship (Schlaegel 1971). Present site index curves for aspen are anamorphic, which assumes that, regardless of site, every stand will follow the same height-growth pattern. It has been shown for other species that the shape of height-growth curves differ from site to site; i.e., they are polymorphic (Stage 1963, Beck 1971). This also appears to be true for aspen but polymorphic curves have not yet been developed.

Soil factors that influence aspen site index are aspect, slope percent, slope position, silt-clay ratio, depth to water table, pH, and rock content.

Many other factors may also influence aspen height growth. Aspen has high genetic variability. Past fire history may affect site quality (Stoeckeler 1948) and

could change the growth pattern. Insect attacks and ice storms may reduce height growth for several years. Past cutting practices can also affect the development of the present stand; commercial clearcuts may have left poor quality trees.

## STAND COMPOSITION OBJECTIVES

A large portion of our present aspen stands are a mixture of several species. These species are in competition for water and soil nutrients. One objective of aspen management is to obtain pure aspen stands, which have lower regeneration costs. If, at the time of the final cut, the stand has a large volume of unmerchantable species, an investment must be made to remove them so a dense sucker stand will result. Any unwanted hardwood reproduction can be removed early in the rotation or when thinning the aspen. If undesirable species are removed early, regeneration costs will be minimized at final harvest.

A pilot study established in north-central Minnesota tested such a thinning in a 10-year-old aspen stand. All undesirable hardwoods were removed and the stand was thinned to about 750 stems per acre. The results were compared with those from a combined cleaning and liberation cutting in which the undesirable hardwoods were removed and the aspen was left unthinned, and from a control area where no cutting was done. When the study was installed the aspen averaged 2,800 stems per acre, and other hardwoods 148 stems per acre. The other hardwoods were

in two age classes: sprouts and seedlings 10 years old, and older trees ranging from 20 to 40 feet tall that had been unmerchantable when the previous stand was cut.

After 19 years the control area had considerably less aspen volume and basal area than either the thinned area or the cleaned area (table 1). The cleaned area had the highest basal area and volume. The volume of merchantable trees (3.6 inches d.b.h. and larger) was similar on the two treated areas. However, the average merchantable volume per tree was 32 percent greater on the area that was thinned. Thinning also produced approximately twice as many trees 8 inches d.b.h. and larger, which are potential veneer trees.

This illustrates the importance of hardwood removal early in the rotation. Both cleaning and thinning increased merchantable volume of aspen by about 30 percent at age 29, and thinning concentrated the volume growth on selected aspen trees.

## THINNING EFFECTS

Thinning aspen stands stimulates tree growth, increases the total yield of merchantable material, and increases the net value of the products harvested during the rotation. In general, aspen stands of a given age on a given site will produce the same volume for a fairly wide range of stand densities. Thus, thinning merely puts the growth on fewer selected trees.

At what age and to what density should the thinning be done? Fifteen years after weeding treatments in a 1-year-old sucker stand in Minnesota that left densities ranging from 260 to 1,500 stems per acre, the average diameters of the 200 and 400 largest trees were similar (Sorensen 1968). After 20 years, largest volume and highest quality trees were on the unthinned control. Natural pruning was less effective on the low density plots, resulting in extreme branchiness and poor bole quality. Thus, reducing the stand density at 1 year of age does not seem advisable.

Although reducing stand density in the first year of the rotation is not recommended, thinning may be desirable early in the rotation. It should be delayed until the trees are large enough so that potential crop trees can be selected with a high degree of confidence. A thinning study in a 20-year-old stand tested square spacing treatments of 10, 15, and 20 feet, and an unthinned control. At age 50 years, 30 years after thinning, the 10-foot spacing and the control area were essentially equal in total volume (table 2). However, all thinned treatments had more trees 10 inches d.b.h. and larger than the control, with the 15-foot spacing having the most.

Because thinning costs money, a more practical approach may be to postpone the first thinning until it will yield some merchantable volume. One successful procedure is to make a moderate crown thinning at age 30 leaving about 275 crop trees per acre. In Minnesota, such a thinning yielded nearly 15 cords per acre. After 32 years, cordwood and saw-log

Table 1. — *Stand density and volume 19 years after removal of undesirable hardwoods and precommercial thinning in 10-year-old aspen*

Item	Aspen thinning and hardwood removal	Hardwood removal only	No cutting
Basal area (sq. ft./acre)			
All aspen	90	104	76
Aspen 27.6 in d.b.h.	36	12	20
Number of trees/acre			
All aspen	419	676	438
Aspen 27.6 in d.b.h.	95	47	53
Volume/acre			
Cubic feet <sup>1/</sup>	2,240	2,600	1,820
Cords <sup>2/</sup>	25.9	27.8	19.9
Cords <sup>3/</sup>	8.5	4.3	4.7

<sup>1/</sup> Total inside bark cubic-foot volume of all aspen 0.6 inches d.b.h. and larger.

<sup>2/</sup> Inside bark volume to a 3-inch top of all aspen 3.6 inches d.b.h. and larger.

<sup>3/</sup> Inside bark volume to a 3-inch top of all aspen 7.6 inches d.b.h. and larger.

volumes were similar in the thinned stand and in the control; but actual volume growth was 32 percent more and total cordwood production was 16 percent higher in the thinned stand. Such thinnings must leave enough trees so that the crowns close within a fairly short time, reducing the invasion of brush and other tree species in the understory.

Table 2.—*Stand density and volume 30 years after thinning in 20-year-old aspen*

Item	Spacing (feet)			
	10 by 10	15 by 15	20 by 20	Control
Basal area (sq. ft./acre)				
All aspen	99	79	59	100
Aspen 29.6 in. d.b.h.	47	65	54	35
Number of trees per acre				
All aspen	238	134	80	266
Aspen 29.6 in. d.b.h.	77	91	68	56
Volume per acre				
Cubic feet <sup>1/</sup>	2,880	2,225	1,660	2,940
Cords <sup>2/</sup>	26.6	20.8	15.4	26.5
Cords <sup>3/</sup>	17.4	22.8	19.1	14.7

<sup>1/</sup> Total inside bark volume of all aspen 0.6 inches d.b.h. and larger.

<sup>2/</sup> Inside bark volume of all aspen 3.6 inches d.b.h. and larger to a 3-inch top.

<sup>3/</sup> Inside bark volume of all aspen 9.6 inches d.b.h. and larger to a 5-inch top.

Thinning in stands nearing rotation age is not recommended. A thinning in a 37-year-old stand did not increase either total volume production or the number of veneer-sized trees after 10 years (Schlaegel and Ringold 1971).

Merchantable volume production will be greatest under intensive management, which means precommercial thinning and cleaning followed by several intermediate cuts. This was demonstrated in a series of treatments established in a young aspen stand in Minnesota. After initially thinning at age 13 to densities of 400 to 1,700 stems per acre, intermediate cuts were made at ages 23, 28, and 33 years. Stocking densities between 550 and 975 trees per acre resulted in 51 percent more total net aspen production—standing merchantable volume plus thinning volumes—than the control at 48 years of age. Only 48 veneer trees 10 inches d.b.h. and larger per acre were found on the control, compared with 132 veneer trees per acre on the intensively thinned plots, an increase of 175 percent.

Thus merchantable aspen production can be increased by early stand cleaning and liberation cutting, precommercial thinning, commercial thinning at age 30 years, and combinations of precommercial thinning with intermediate cutting. Recommendations for a

precommercial thinning, age 10 to 15 years, would be to leave from 750 to 900 trees per acre and remove all undesirable hardwoods. Thinning at age 20 should leave from 200 to 400 trees per acre, depending on the final product desired; 200 trees per acre will produce more veneer volume while 400 trees per acre will produce more pulpwood volume. At age 30 years, a crown thinning to about 275 trees per acre results in more pulpwood and veneer production than no treatment.

## GROWTH AND YIELD

The evaluation of thinning must be based on expected growth responses and how they will affect the final yield. Recently data from several studies were analyzed and growth and yield tables were prepared for thinned aspen stands (Schlaegel 1971).

Total cubic-foot yield (Y) can be estimated from stand basal area (B) and average stand height (H):

$$(1) Y = 0.41898 (BH)$$

Merchantable cubic-foot stand volumes to a 3-inch top (V3) and a 5-inch top (V5) can be estimated from total cubic-foot yield (Y) and average stand diameter (D):

$$(2) V3 = Y [0.9858 - 5.4737 (0.4876)^D]$$

$$(3) V5 = Y [0.9804 - 12.3277 (0.57)^D]$$

They can then be converted to merchantable cords per acre (table 3). However, to estimate future yields, the future values of the stand basal area, average stand height, and average stand diameter must be predicted.

Net periodic annual basal-area growth (BAG) is essentially constant for a broad range of sites and has relatively little change with basal area densities, but decreases rather rapidly with increasing age (table 4). Basal-area growth can be estimated from the table and added to the present basal area to obtain an estimate of future basal area.<sup>1</sup>

Estimates of future stand height can be obtained from a set of site-index curves. Using the estimates of future stand basal area and height, future total stand volume can be estimated from Equation 1.

<sup>1</sup> Additional information on projecting stand basal area is given in Schlaegel (1971).

Table 3. — *Aspen yield by site, age, and stand density*

SITE INDEX 90												
Merchantable cords (to 3-inch and 5-inch top diameter) per acre when basal area density is--												
Age	Ht.	40		60		80		100		120		140
(years)	(feet)	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	3-in.	5-in.	5-in.
20	58	9	0	12	0	13	0	11	0			
30	74	15	10	21	12	27	10	31	4	33	0	29
40	83	17	15	26	22	34	26	41	28	47	25	52
50	90	19	18	28	26	38	34	46	41	54	44	62
60	94	20	19	30	29	39	38	49	47	59	54	68
SITE INDEX 80												
20	52	8	0	11	0	11	0	10	0			
30	66	13	9	19	11	24	9	28	4	29	0	25
40	74	15	14	23	19	30	23	37	25	42	22	46
50	80	17	16	25	23	33	31	41	36	48	39	55
60	84	18	17	26	26	35	34	44	41	52	48	61
SITE INDEX 70												
20	46	7	0	10	0	10	0	8	0			
30	57	11	8	17	10	21	8	24	3	25	0	22
40	65	13	12	20	17	26	20	32	21	37	19	41
50	70	15	14	22	21	29	27	36	32	42	34	48
60	73	15	15	23	23	31	30	38	36	46	42	53

Table 4. — *Net periodic annual basal area growth by age and stand density*

Total stand age (years)	Basal area (in square feet per acre)						
	20	40	60	80	100	120	140
20	2.39	3.40	3.89	4.03	3.92	3.62	3.14
25	1.92	2.72	3.11	3.23	3.04	2.89	2.51
30	1.60	2.27	2.59	2.69	2.62	2.41	2.09
35	1.37	1.94	2.22	2.30	2.24	2.07	1.79
40	1.20	1.70	1.94	2.02	1.96	1.81	1.57
45	1.06	1.51	1.73	1.79	1.74	1.61	1.40
50	.96	1.36	1.56	1.61	1.57	1.45	1.26
55	.87	1.24	1.41	1.47	1.43	1.32	1.14

Average stand diameter growth was linear for aspen between the ages of 10 and 60 years and averaged 0.184 inches per year after the initial thinning. Therefore, future stand diameter ( $DBH_f$ ) at age  $A_f$  can be estimated from Equation 4 by using the initial stand age ( $A_i$ ) and diameter ( $DBH_i$ ):

$$(4) DBH_f = 0.1841 (A_f - A_i) + DBH_i.$$

Future merchantable yields can then be computed with Equations 2 and 3.

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# THE BASIC HABITAT RESOURCE FOR RUFFED GROUSE<sup>1</sup>

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**ABSTRACT.** — There is a close correlation between the distribution of the aspens and of ruffed grouse. (*Bonasa umbellus*) both on a continent-wide and local basis. As an aspen stand regenerates from destruction by fire or removal by cutting and progresses towards maturity, it is continuously providing some of the needs of grouse at some stage of their annual life cycle. Aspen leaves and staminate flower buds constitute the most important year-long food resource. As the aspen regeneration thins from high density sucker growth through the sapling stage to the pole stage and finally mature timber, best quality cover is provided for ruffed grouse broods, wintering and breeding grouse, and finally nesting hens. But to sustain highest density grouse populations these age classes must all be available to each wintering and breeding grouse within a normal foraging range of about 10 acres.

## GENERAL RUFFED GROUSE - ASPEN

### RELATIONSHIPS

At least 100 years ago Parker Gillmore made an observation that has since been overlooked by too many generations of wildlife and forest managers: "In the undergrowth which springs up in that portion of the country [Maine] where timber has been destroyed by fire, I ever found them [ruffed grouse] very abundant, it being almost impossible to wander half a mile through such openings without flushing a covey" (Jasper p. 121 in Studer 1888). Judging by the forest composition now in recently burned Maine forests, it seems probable that most of the "undergrowth" seen by Gillmore consisted of aspen regeneration.

Also, it is probably no accident that the North American distribution of the aspens fairly closely delimits the native distribution of the ruffed grouse as

well (fig. 1) (Bailey *et al.* 1955). There are some places where aspen is common in North America where these grouse do not occur; and there are ruffed grouse populations in the southern Appalachians, some parts of the Midwest, and on the Pacific coast where aspen is absent. Recent successful introductions into the Beaver group of islands in Lake Michigan (Moran and Palmer 1963), the Ruby Mountains in northeastern Nevada (Hoskins 1968), and into Newfoundland (Inder 1967) suggest that isolated aspen forests lack these grouse simply because the birds have failed to disperse into them. On the other hand, it is only in the warmer climates where grouse encounter less severe wintering conditions that they persist in the absence of aspen; and though sometimes locally common in these peripheral habitats, ruffed grouse seldom approach the widespread abundance common in the more northern regions where aspen is, or was, a dominant component of the forest.

### Minnesota Studies

From a 15-year study of ruffed grouse — forestry relationships on and in the vicinity of the Cloquet Forestry Center in east-central Minnesota, it has become apparent that at some time during the regeneration and growth of an aspen stand, these trees

<sup>1</sup> Paper No. 7854 *Scientific Journal Series*, Minnesota Agricultural Experiment Station, University of Minnesota, St. Paul. This paper reports progress on the Forest Wildlife Relations Project 83H; the Minnesota Agricultural Experiment Station, College of Forestry, and the Minnesota Division of Game and Fish cooperating.

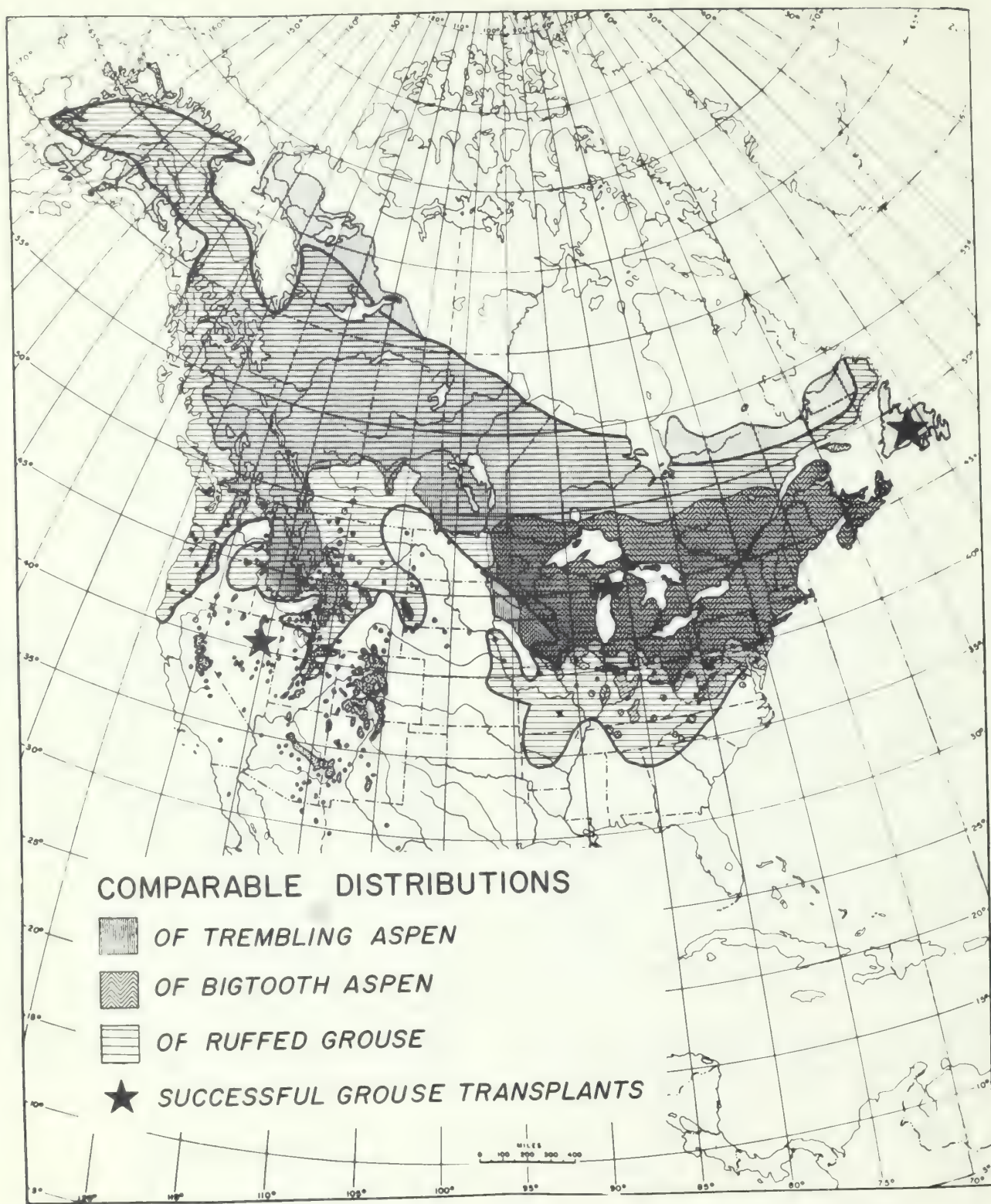


Figure 1. — Distribution of the North American aspens and ruffed grouse. The distribution of the aspens from Fowells (1965); the distribution of ruffed grouse based on Aldrich (1963); base map from Fowells (1965).

meet every need of the ruffed grouse at some stage of the bird's life history. If the habitat available to grouse contains a mosaic of aspen age classes within the restricted foraging range of ruffed grouse, aspen alone can meet all the habitat needs of resident grouse throughout the year, from brood cover for chicks through essential food resources and winter and spring breeding cover for the grown birds to nesting cover for the hens. No other species of shrub or tree in North American forests appears to fill the needs of ruffed grouse so adequately.

Fortunately, the aspens are not only "the most widely distributed tree species in North America" (Fowells 1965) but are economically important as well (Schneider 1970). It is hardly surprising therefore that the ruffed grouse has a larger North American range than that of any other resident game bird (Edminster 1954).

### **The Function of Aspen as a Resource for Grouse**

To understand how the aspens function as a basic habitat resource of ruffed grouse we first need to consider briefly the basic habitat needs of these birds. Food, cover, and water are the three basic needs of living animals. A lack of free water for drinking probably seldom limits a browsing species such as grouse. But insufficient food and cover may be limiting even in extensive forested areas.

### **Food — A Factor Limiting Grouse Occurrence**

Although wildlife biologists generally have long discounted food shortages as a threat to ruffed grouse populations in hardwood forests, our studies at Cloquet have shown that statements such as "When its preferred foods are used up . . . it can always turn to tree buds, the supply of which is virtually inexhaustible . . ." (Edminster 1954) are probably erroneous. The food resource for ruffed grouse is probably much less catholic than formerly believed.

During a series of winter "feeding runs" extending through the period when snow covered the ground during the winters from 1965 to 1970 we found that ruffed grouse fed on the flower buds of the male aspens six times as much (in relation to availability) as upon all other hardwood species combined. In

1967-68 this preference reached 13 to 1 (Svoboda and Gullion, unpublished data).

Furthermore, examination of several thousand ruffed grouse droppings collected at Cloquet from 1964 through 1969 provided the basis for the statement by Vanderschaegen (1970), "The most important food plants for ruffed grouse in the Cloquet area are aspens. Aspen buds, catkins, or leaves were used at all seasons of the year. Aspen buds (both vegetative and male flower) are the number one winter food, male buds and catkins the number one spring food, and buds and leaves the second most important fall food." Vanderschaegen found that even during summer the leaves were a most important source of food, constituting more than 53 percent of the identifiable material examined and outranking five-fold the second most important — the seeds of sedges (*Carex* spp.).

Beaked hazel (*Corylus cornuta*) ranked second overall, but under some conditions can be *most important* as a winter food resource. Catkins of the birches (*Betula papyrifera*; *B. lutea*) never ranked better than a poor third, and ironwood (*Ostrya virginiana*), often considered important elsewhere (Stollberg and Hine 1952) is rare in the Cloquet Forest.

The arrangement of flower buds and physical characteristics of the aspen twig are probably important to ruffed grouse. The twig is rigid and usually enters the fall season with 6 to 8 easily detached flower buds near the tip (fig. 2). This combination allows grouse to take their evening meal quickly and quietly before they dive into a snow burrow for the night.

We have observed ruffed grouse taking flower buds at a rate exceeding 45 per minute. Birds feeding in aspen seldom spend more than 15 to 20 minutes collecting the 90 to 100 grams of buds that constitute a meal. This compares to a 150-pound human consuming about 27 pounds of food in 15 to 20 minutes.

Grouse cannot feed as rapidly or effortlessly on any of the other arboreal foods available to them. Rapid feeding has two distinct advantages for grouse: (1) it minimizes their accessibility to predators (an evening feeding period beginning about sundown coincides with the early foraging flights of horned and other owls) and (2) short feeding periods reduce the expenditure of energy needed to keep warm during



Figure 2. — A terminal twig of trembling aspen showing three typical clusters of staminate flower buds and the apical vegetative buds.

cold winter evenings. During the colder part of winter ruffed grouse are in snow burrows almost continually, perhaps as much as 23 hours a day, except for their brief emergence to feed hastily upon a readily available food such as the aspen flower buds.

When snow is deep and crusted ruffed grouse may spend much more time feeding on the hazel catkins they can reach from the snow surface—but when conditions favorable for this type of feeding persist winter losses of grouse also increase.

Huff (1970) has shown the male flower buds of aspens to be one of the richest sources of nutrients available to these birds through the winter when snow lies on the ground.

Observations over the past 6 years show that ruffed grouse prefer certain clones of aspen for feeding. Huff's analyses (1970) have shown the flower buds

from preferred clones of trembling aspen to be about 30 percent richer in protein (14.2 vs. 10.9 percent dry weight) than flower buds taken from male aspen clones where we have seen no feeding use by ruffed grouse for the past 13 years.

Contrary to the belief that ruffed grouse are forced into arboreal feeding by snow covering their ground-level resources, we have found that heavy and sometimes exclusive use of staminate flower buds of the aspens begins many weeks before snow covers the ground.

Our earliest record of use of aspen buds is of a 13-week-old male ruffed grouse feeding in aspen on September 30, 1964 (Godfrey 1967).

In spring at least the male ruffed grouse continue to use the developing staminate catkins of aspen almost to the exclusion of other food until the aments have shed their pollen, dried, and begun falling from the twigs in early May. Only then do the grouse commence using the evergreen, frost-resistant herbs (e.g., *Cornus canadensis*, *Coptis groenlandica*, *Gaultheria procumbens*, *Fragaria* spp., *Linnea borealis*) that have been available to them at ground level since the snow melt—which may have been complete as much as 3 to 5 weeks prior to aspen catkin maturation at Cloquet.

In addition to our observations of grouse feeding preferences over a 6-year period, the analysis of droppings collected from 1964 to 1969, and the analyses of nutritional values from 1968 to date, we have further evidence of the dependence of grouse upon the aspen for food. All the previously perennially occupied breeding activity centers from which aspen was cut were abandoned by grouse even though their drumming logs were not disturbed and both hazel and birch remained in virtually their precutting abundance. At least 11 of these centers have gone "full-cycle" and now are being reoccupied by grouse 7 to 13 years after cutting.

On the Cloquet Forestry Center there are large pine stands from which all or most of the aspen has been removed through timber stand improvement. These stands are devoid of breeding ruffed grouse, even though adjacent tracts where aspen remains uncut among the pine canopy had breeding grouse densities as high as one bird per 6 acres in 1971 (this

compared with one breeding grouse per 3 acres in best quality aspen stands).

On the Bob Lake portion of the Cloquet study area there are two tracts of northern hardwood forest from which aspen was selectively cut in about 1960, leaving a forest of maple, oak, paper birch, basswood, ironwood, and some other hardwoods intact. Both of these tracts have been devoid of breeding ruffed grouse since we began studying them in 1965: one is 218 acres in extent, the other 95 acres. On adjacent areas where soil and topography are the same but aspen remains in the forest canopy, we had a breeding ruffed grouse density exceeding one bird per 6 acres in 1971.

We believe it is also significant that more than 98 percent of the persistently used drumming logs on both our Cloquet study area (including 247 logs occupied in 1971) and on 2,800 acres of the Mille Lacs Wildlife Area (94 occupied logs in 1971) are within sight of mature *male* trembling or bigtooth aspen.

### **Aspen Meets the Spectrum of Cover Needs of Ruffed Grouse**

Aspen in various age classes best provides the quality of cover needed by ruffed grouse at various stages of their annual life cycle. But first we need to reconsider what constitutes secure cover for ruffed grouse. Some types of cover, long considered to be essential to grouse, provide better hunting cover for the major grouse predators and so are actually detrimental to the maintenance of high density ruffed grouse populations (Gullion and Marshall 1968).

Analysis of the longevity of 446 drumming male grouse over a 11-year period has shown that the longest lived grouse occupy sites where the stems of sapling aspen, hazel, mountain maple, alder, or other hardwood species provide a dense stand of small diameter (under 6 inches) stems. This we call "vertical cover" and believe that this quality of cover is not only most effective in protecting the birds from surprise attack by raptors (hawks and owl) overhead but also allows the bird to maintain effective surveillance for mammalian predators on the ground for a radius of 50 to 60 feet at all times.

The less secure cover, which we call "horizontal cover," provides effective hunting or ambush cover

for the animals that commonly prey upon ruffed grouse. Brush piles, slashing, windfalls, and the boughs of conifers both close to the ground and in the forest canopy all provide such cover for grouse predators.

Several brush species substitute structurally for aspen stems as adequate vertical cover for ruffed grouse. But none of these can be managed as easily, provide a year-long food resource, or have the economic value of the aspens. Furthermore, none of the other northern hardwoods regenerates as root suckers after being cut in the same manner as aspen, producing a fairly uniform, dense stand over a large piece of ground. Nor do any other hardwoods provide an adequate food resource for these grouse as the trees mature.

Specifically, the young regenerating sucker growth of aspen can provide in its first year high quality brood habitat for grouse by the time the chicks hatch in mid-June, following winter clearcutting or early spring burning. As the regeneration grows it continues to provide a high quality brood habitat for perhaps as long as a decade following the initial removal of the stand by logging or fire, especially if it is growing on a low, moist site.

At about 10 years of age in northern Minnesota, the aspen growth has gone through its first natural thinning and developed into a sapling stand 25 to 35 feet high that has a density of less than 8 thousand stems per acre. Then it provides a good quality cover for wintering and breeding ruffed grouse. In both 1970 and 1971 our average grouse spring density was a breeding bird per 4 acres in the 8- to 12-year old aspen regeneration at Cloquet.

Natural thinning continues as the aspen stand grows toward pole-size, and the value of the stand to ruffed grouse increases as space between stems increases and the canopy grows higher overhead. The 13- to 25-year old aspen stands on the Cloquet area supported a breeding grouse per 3 acres in both 1970 and 1971.

But when the stand density thins below roughly 2,000 stems per acre, at about 25 years of age at Cloquet, long-occupied coverts rather abruptly become devoid of breeding ruffed grouse. However, it is at about this age that the aspen flower-buds commence being used as a winter-long food resource; and the

more open, park-like aspen stand appears to be the most secure nesting cover for ruffed grouse hens. Most hens select nesting sites where they can fly directly from the nest into the crowns of male aspen to feed upon the new-grown leaves (Barrett 1970, Kupa 1966, Schladweiler 1968).

### Earliest Snow-cover Is Available In Aspen Stands

Depth of winter snow is an environmental factor of critical importance to ruffed grouse in northern Minnesota (Gullion 1970). Ruffed grouse survive the winter best when they can bury themselves in 8 or more inches of soft, powdery snow.

In northern Minnesota snow reaches satisfactory depths earliest in aspen and hardwood stands. During some winters snow depths under closed canopy conifer stands may never reach adequate depths, and the grouse depend all winter upon the snow accumulation in the hardwoods for adequate roosting snow.

### Grouse, Aspen, and Forest Management

Combining what we know about ruffed grouse needs and behavior and the silvicultural requirements of the aspens (Graham *et al.* 1963), it appears that there are three important considerations in managing northern forests where ruffed grouse for recreational hunting is an important goal:

1. Aspen must be maintained in the forest composition;
2. Forest stands containing aspen must be clearcut when logged to preserve aspen clonal stock and to encourage high-density sucker regeneration; and
3. Cuttings must be small enough and spaced both in distance and years so that at least three age classes of aspen (preferably four) are available to grouse on each of the 10-acre breeding activity centers that appear to represent about the highest density grouse population (a bird per 5 acres) we can expect under most conditions.

This management of both aspen as a wood resource and ruffed grouse as a wildlife resource can best be achieved by clearcutting aspen on a 10- to 50-year rotation, cutting no more than 10 acres out of any 40 acres at one time, and spacing the logging at about 10-year intervals.

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# MANAGEMENT FOR DEER

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**ABSTRACT.** — Deer in the Lake States are declining. Early stages of second growth forest following the logging era favored deer. Aging and successional changes toward more tolerant types are causing range deterioration. Aspen is the major deer-producing forest type. Commercial harvest of aspen improves deer range, but not enough is taking place to reverse the downward trend of deer or to save the type from conversion. Additional efforts to cut or otherwise treat aspen stands specifically for deer have been of token size. Michigan has earmarked a deer license increase for range improvement and is now embarked on a large scale habitat management program aimed principally at aspen types.

## DEER AND ASPEN IN THE LAKE STATES

The history of the white-tailed deer is so involved with that of the aspen, aspen-birch, and spruce-fir forest types of the Lake States area that any discourse regarding the deer's fate must include the story of recent changes in these forest types and a projection of their future.

The original great forests of the Lake States were for the most part logged off by 1920 (Dahlberg and Guettinger 1956, Swift 1946). In the wake of early logging deer populations peaked at various times between 1850 and 1900. This was a response to the improvement in deer range that immediately followed the vast clearcutting. Herds were again reduced to a new and possibly all-time low between 1890 and 1910 as a result of the habitat destruction caused by widespread forest fires and uncontrolled hunting of deer for market. From 1910 through 1950 deer populations again increased as the cutover and burned-over land of Minnesota, Wisconsin, and Michigan was reclothed with aspen, birch, oak, jack pine, northern hardwood reproduction, and shrubs. Greatly improved forest fire protection along with more restrictive game laws enabled deer to fully occupy this new habitat.

These large deer herds were for the most part underharvested from 1930 through 1950 (Jenkins

and Bartlett 1959, Dahlberg and Guettinger 1956, Erickson *et al.* 1961). Light deer harvests, the bucks-only laws, and some closed seasons caused serious overbrowsing in winter range by the 1930's. Since 1930, maturing of the aspen stands, chronic overbrowsing, and conversion to conifers through natural plant succession have greatly reduced the carrying capacity of the Lake States deer range.

The deer-producing cornucopia of second growth trees and shrubs has emptied and at the present time game managers and administrators face a confused public, which in general displays a naivete toward any biological or ecological explanation of the deer-food problem or any prescription for maintaining a reasonable deer herd. The current situation is similar to that described by Dahlberg and Guettinger (1956) during the early decades of deer problems in Wisconsin. For many reasons people who decide what happens in the Lake States believed in regulating the harvest of deer rather than the total management of the resource, which would have included improvement of the range.

After 20 years of harvesting as many deer as politically acceptable liberal deer seasons would permit, the Lake States deer herd is probably headed toward a population low that will not provide a reasonable or adequate hunting-recreation opportunity. In Michigan, hunter numbers have increased since 1964, while

the kill has decreased from the 1964 bag of 141,000 to 60,000 in 1971. In Minnesota the decline in the deer take began in 1966. The harvest dropped from 103,000 in 1968 to 67,000 in 1969. There was a closed season in 1971. Wisconsin dropped from a peak harvest in 1967 of 128,000 deer down to 72,000 in 1970. It is becoming increasingly apparent that antlerless deer harvests cannot be continuously substituted for deer range renovation if even a reasonable fraction of the deer populations that existed between 1930 and 1960 is to be produced and sustained.

The high population of deer in the Lake States in the past was a result of severe forest disturbance over a long period of time. The composition of forest cover that emerged set the stage for a tremendous increase in deer numbers. The heyday of deer production that resulted from the new composition of cover is now beginning to bottom out. However, the basic forest composition that was so productive of deer food and cover in the past still occurs in approximately the same proportions and locations as it did in the more productive years. But now, in the early 1970's, it is important to recognize that this cover composition is changing fast. The natural process of plant succession is adversely affecting the deer habitat at a rapid rate in the Lake States forests and it appears that the greatest change will occur in the next 10 years. The species involved are basically the following: aspen, paper birch, scrub oak, jack pine, and the herbaceous plants and shrub communities that form their understory as a result of adequate light. The openings so essential to deer are also more abundant in these intolerant types.

Aspen and aspen-birch are the types that seem most likely to provide adequate deer food — browse from shrubs and young trees associated with the types and from the young aspen (Rutske 1969, Grange 1949). Aspen leaves are a preferred summer food in Wisconsin (McCaffery 1970). McCaffery and Creed (1969) found more deer in the aspen type than in all others during the summer months. Minnesota game men found that aspen stands under 30 years old are preferred deer range. In Michigan, the Phoenix Project studies have shown the close relationship of aspen communities and deer, and they emphasize the impact that proper management of this forest type can have on deer populations (Westell 1954, 1955, and 1960; Graham *et al.* 1963).

The most important deer-producing areas in Michigan are predominantly aspen areas. Department of Natural Resources mail surveys of deer hunters for the years 1961-1965 reveal that 360 townships produced 75 percent of the deer taken each year. These areas, totaling 13,000 square miles, comprise only 39 percent of the region's total northern forest type. In these townships aspen is the most frequently occurring forest type. The ownership pattern within them is 25 percent State, 11 percent Federal, and 64 percent private. A further look at statistics from 12 counties that include about half of the above townships shows that a highly significant correlation ( $P < 0.01$ ) exists between the average buck kill per county and the acreage of the aspen type in the county (fig. 1).

This close correlation could mean simply that deer in these counties are closely related to forested land in general, and that the aspen acreage merely reflects the overall forest influence. To test this hypothesis we computed a regression of deer kill on acreage of total commercial forest land and found no significant correlation (fig. 2). We conclude, therefore, that aspen is the strongly influencing factor.

This evidence convinces us that aspen forests are the major deer producers in our area, and it clearly points out where the emphasis of our range management efforts should be applied.

There are about 51 million acres of commercial forest land area in Minnesota, Michigan, and Wisconsin. Eighteen million acres (35 percent) are occupied by the aspen-birch forest type group.<sup>1</sup> Minnesota has 5.5 million acres of aspen type alone, Wisconsin 3.5 million acres, and Michigan 4.5 million acres, a total of 13.5 million acres or about one-quarter of the total commercial forest land area in the Lake States. About half of the aspen type is publicly owned. The Lake States have an overabundance (from a deer standpoint) of aspen in the 30-to-60-year age class. Aspen is growing faster than it is being cut. If this

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<sup>1</sup> Lundgren, Allen L. *Economics of aspen management. A paper presented at joint meeting of Great Lakes Deer Group and The Ruffed Grouse Workshop, Quadna Mt. Lodge, Hill City, Minn., Sept. 22, 1970.*

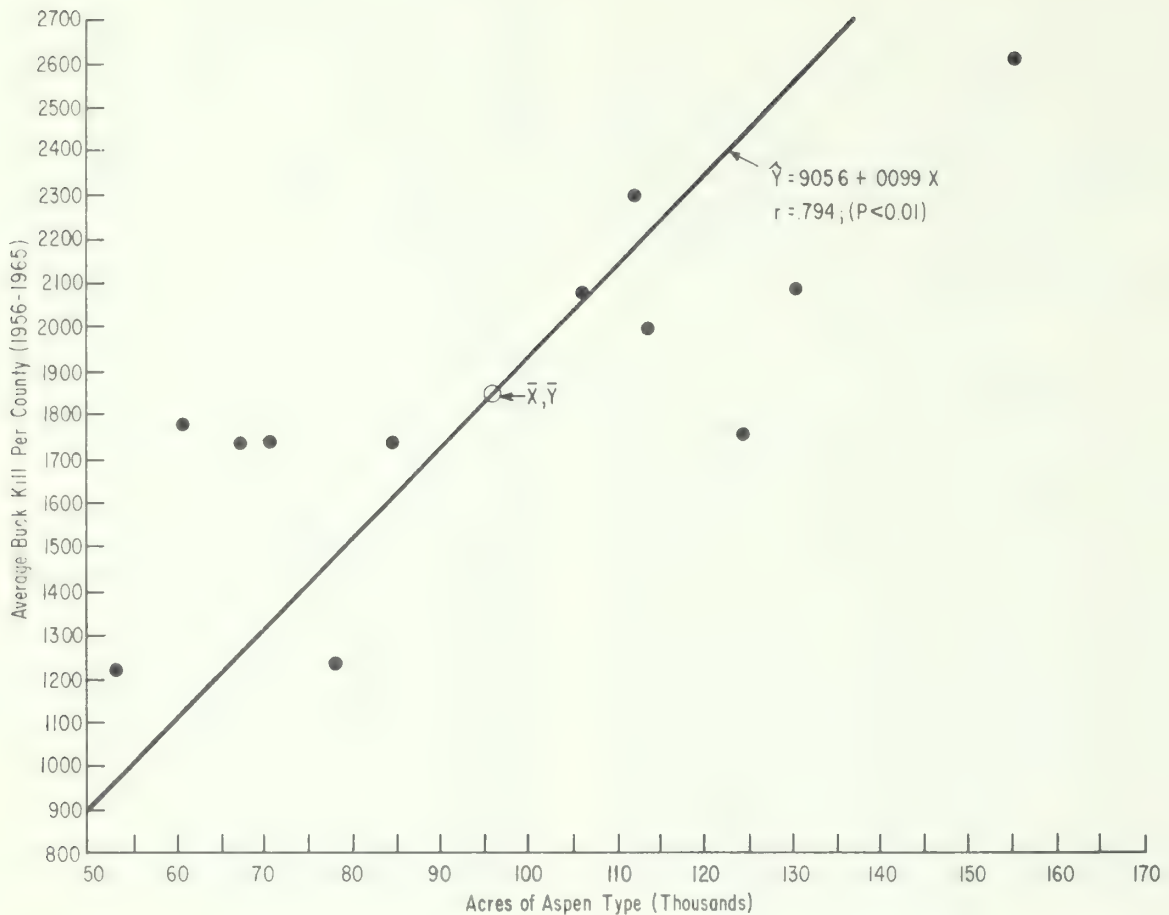


Figure 1. — A regression and correlation of average estimated buck kill per county from mail survey reports (1956-1965) with acreage of aspen type for 12 Lower Michigan counties.

older aspen is not cut it will convert to more stable, more tolerant, forest types such as northern hardwoods, spruce-fir, or pine.

Lundgren<sup>1</sup> estimates that we are at present cutting 200,000 acres per year of the aspen type out of a possible 300,000 acres per year, based on a 40-year rotation. In theory then, a 300,000-acre cut could be maintained indefinitely. Much additional aspen occurs in other types of the aspen-birch group. Because one-third of the Lake States forest land is in the aspen-birch group, we can assume that a similar proportion of the region's forest is potential good deer range. Other forest types, of course, contribute to the carrying capacity of the range, but to a lesser degree.

Some foresters in Michigan point out that older, less well-stocked stands of aspen are changing to other forest types through natural succession. Absence of fires after 1935 and limited acreage of clearcutting of mature aspen have resulted in fewer aspen stands being originated than before. During the rapid increase of maturing aspen between 1955 and 1970, supply was ahead of demand and caused some concern about an aspen surplus. Estimates of allowable cuts continued to increase, reflecting accumulation of volumes in mature aspen stands (many of which were poor quality), small stands in other forest types, and overstories in swamp conifers economically unattractive to loggers. Aspen cutting has not kept up with the incidence of early fires, and regenerated stands

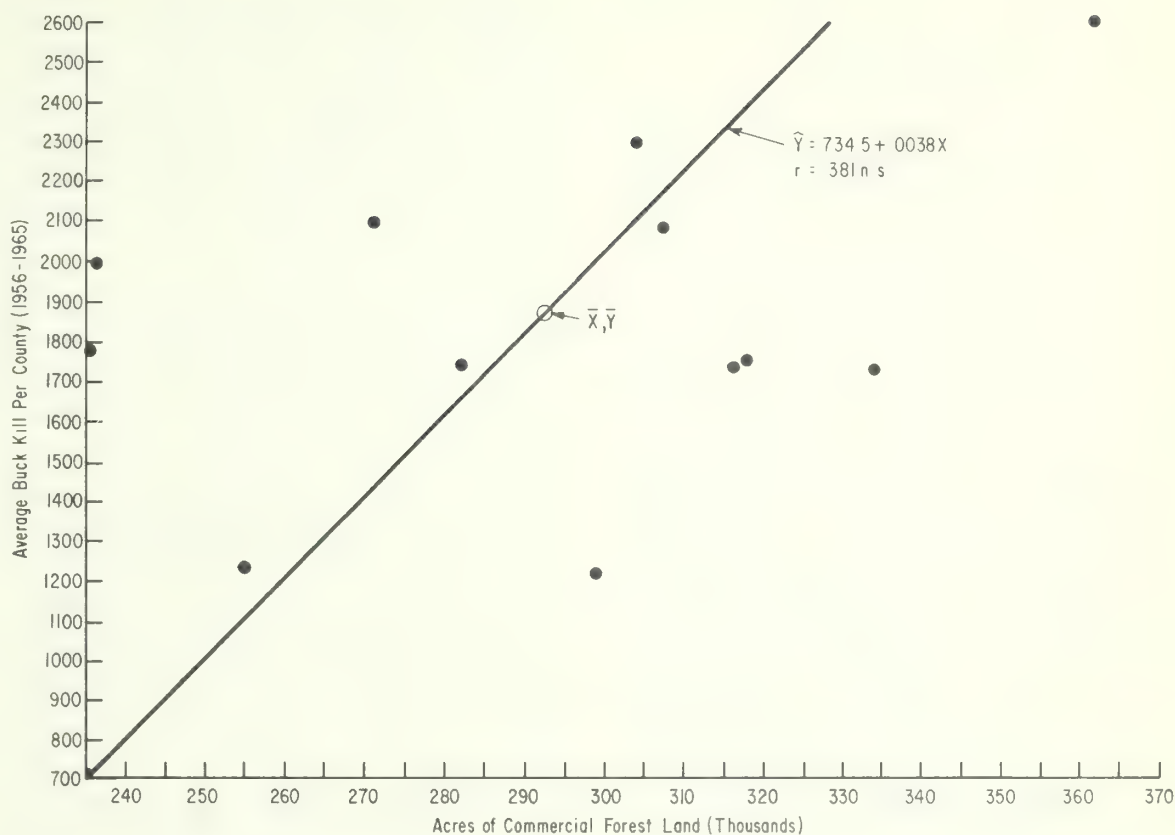


Figure 2. — *A regression and correlation of average estimated buck kill per county from mail survey reports (1936-1965) with total commercial forest land for 12 Lower Michigan counties.*

have not equaled the original post-fire volunteer acreage. Foresters now predict that there will be a shortage of good quality aspen by 1980, that supply will not keep up with demand, which should remain relatively high, and that other species will be substituted for aspen as a source of pulpwood.

### MANAGEMENT OF ASPEN FOR DEER IN THE PAST

Continuous cutting or otherwise removing overstory are the major biological manipulations needed to maintain and renew potentially productive deer range. In addition to yearly commercial wood harvests, State game agencies in Wisconsin, Minnesota, and Michigan have been making forest cuttings specifically to improve deer range.

In Minnesota during 1969 and 1970, 12,000 acres, primarily in the aspen-birch type, were cut, burned, or otherwise improved. Access roads were constructed to improved areas. A similar effort will be made in 1972 and 1973. A Wisconsin deer range maintenance program started in 1969 when about 22,000 acres in the aspen-birch type were cut. Cuttings were designed to maintain the aspen type. Since 1958, Michigan has cut 48 square miles of poor-quality aspen, aspen-birch, and mixed aspen-hardwood with tree-cutter bulldozers, and 21 square miles of aspen-birch and low-land species by handcutting crews to improve deer range (Cook 1969). These cuttings were near deer yards and were designed to provide deer food by producing sprout growth of aspen and associated species. Totalling 44,000 acres, they were a small effort when compared to the 10 million acres of aspen-birch,

maple-birch, and spruce-fir forest type in Michigan, especially because the 44,000 acres have been cut over a 14-year period. In the three States combined the annual cutting specifically for deer the last 3 years has averaged 10,000 acres.

Obviously the best efforts of game agencies in the Lake States to mount a habitat renovation program of significant size has so far failed. Such efforts to be successful would have to involve large areas of the aspen and aspen-birch forest types in the three States. It would be as unrealistic to suggest that the entire forest be changed to create ideal habitat as it would be to declare that the problem is so vast that it is hopeless. During the next few decades an increasing proportion of our forests will undergo some type of alteration due to man's capacity to manipulate resources for profit and other motives. The overall plan for future forest management should be designed to include the production of wildlife as well as wood. Such a plan should accelerate recycling of forest succession at a rate in excess of that realized only from commercial harvest of forest products.

Jordan (1970) believes that a new approach to deer-habitat management is needed and advocates the development of systems of deer-food management as a method of solving deer food problems. He states, "Deer habitat management is the planned manipulation and control of vegetation to satisfy food and shelter requirements of deer." The purpose of herd management is to provide a reasonable, stable, and acceptable yield of deer for hunting. Ultimately, the solution of the deer-timber problem must come from better herd management and from development of systems of habitat management that apply habitat practices to specific units of deer range, in an ordered sequence, over a continuous period of time, and that produce predictable effects on deer herds.

Deer range research is not popular with many administrators and politicians because it is costly, is not easily understood, is often a long-term operation, and it deals primarily with vegetation rather than with the animals themselves. One of the most significant drawbacks is that deer are a renewable resource, used directly by an unorganized public (hunting and viewing). They are not a resource extracted by private individuals or groups for profit, or one with a fixed price tag that lends itself to exploitation through established business channels with the attendant po-

litical direction from organized business groups.

Big game license fees are too low in the Lake States (Heuser 1971). They are earmarked for habitat improvement only with extreme difficulty. While \$5.00 deer licenses cover a full season, Heuser points out that it is not difficult to obtain a daily \$8.00 ski lift fee, or a \$5.00 a day golf green fee, or a \$4.00 a day camping fee. Funds could be raised from hunters for adequate research of and for range management if they knew the money would be used for these purposes and would, as a result, improve their hunting. In his Lake States deer problem summary Heuser (1971) emphasizes the competing interest facing big game managers who are under pressure from many groups such as farmers, hunters, resort owners, politicians, nature groups, and public agencies.

### **MICHIGAN'S NEW DEER HABITAT MANAGEMENT PLAN**

The Michigan Legislature in 1971 increased the cost of deer licenses and stipulated that \$1.50 of each license should be used for the maintenance and improvement of deer habitat. This money will now permit, for the first time, the application of a large-scale program of management for deer habitat. The Legislature appropriated \$616,000 for this work in the 1971-1972 fiscal year. An action plan has been developed and is currently being implemented. Its goals and prescriptions for treatment are summarized below:

The goals of wildlife habitat management for the primary deer producing townships in Michigan are to preserve, maintain, improve, and expand the deer range to the extent that it will: (1) Stop the downward trend of deer numbers, and (2) Increase the herd to approximately 25 to 30 deer per square mile.

To accomplish these goals, the primary concern will be to preserve and maintain suitable wildlife habitat that is being lost to regrowth, aging, and conversion. Specifically, management will be concerned with the preservation of the aspen type, forest openings, upland brush, oak, and jack pine in the State Forests. The major emphasis of the plan will be to favor the preservation, improvement, and expansion of the aspen type. Every effort will be made to adhere to the following guidelines for deer habitat improvement:

(1) Maintain a desirable proportion of *aspen type*; not less than 35 percent of upland area.

(2) Preserve, improve, and expand *forest openings*. Aim for not less than 15 percent of upland area.

(3) Manage for the most desirable proportion of *preferred forest types* (aspen, openings, upland brush, oak, jack pine) that are most valuable to deer and other wildlife. These preferred types should cover not less than 60 percent of the upland forest area.

(4) Attain, within the next 10 years, an equitable distribution of different size classes of each forest type in each wildlife management unit. Plan for 25 percent of upland area to be in the 1- to 10-year age class.

(5) The lowland coniferous cover and its immediate upland edge are the most valuable areas for food and cover during the winter months. Manage the upland edge of the lowland cover for long-range food producing areas by maintaining about 25 percent of the lowland perimeter in forest regrowth and openings. In selecting sites for improvement, favor the most protected areas, with the lowest gradient, on the south and east sides. These sites support the widest ecotones with the greatest variety and area of plants.

Commercial cutting will be used as much as possible. Where treatment is required beyond the capability of commercial harvest and subsidized sales, tractor tree cutters, hand-cutting, and prescribed burning will be used as best fits the need.

The scale of this program is large. If goals are reasonably well accomplished, over 400,000 acres of deer range, largely aspen land and openings, will have to be treated within the next 10 years. We feel this should have a significant effect in turning back the

tide of successional range degeneration and restoring deer numbers to levels of past decades for the fullest use and enjoyment of the public.

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# EFFECTS OF THINNING ON GROWTH AND YIELD

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**ABSTRACT.** — Comparative studies of noncommercial and commercial thinnings covering an 18-year period (on the Boise Cascade Corporation Experimental Forest near Loman, Minnesota) demonstrate how quaking aspen diameter growth was increased by thinning thus shortening the rotation.

A 12-year-old noncommercial thinning in an aspen sucker stand and a commercial thinning in a 32-year-old merchantable stand demonstrate how cultural treatment can shorten the rotation age and increase the production of veneer or saw logs in aspen stands.

## NONCOMMERCIAL THINNING

To illustrate what can be accomplished by a non-commercial thinning let's examine such a thinning in quaking aspen sucker stand on our experimental forest. A well-stocked aspen stand (site index 85 to 90) was clearcut during the fall and winter of 1953-54. Seven growing seasons later, six 1/10-acre plots — which were as similar as possible in average tree diameter, stocking, and site — were established in the spring of 1960 in the aspen sucker stand that resulted from the clearcut. The area outside each 1/10-acre plot was expanded to 1/2 acre to serve as a buffer zone and given equal treatment.

Three of these permanent plots were designated as reserve or control plots and three were thinned before the growing season in the spring of 1960 reducing the stem count from 3,750 to 695, giving an 8 by 8 foot spacing and saving the best dominant and codominant trees.

Two of the thinned plots were axe thinned. The work required 9.5 man hours per acre. The other was thinned with 2,4,5-T herbicide. Although this thinning was successful, the herbicide was translocated through the root system to the residual trees, inhibiting growth for a number of years. Therefore, data from this plot were not used.

All trees were remeasured at d.b.h. to 100th inch each fall following the growing season.

Annual average d.b.h. growth in the thinned plots fluctuated from 0.04 to 0.38 inch and the unthinned or control plots from 0.05 to 0.20 inch. The low point in growth was reached during the 1971 growing season when most of the trees were completely defoliated by the tent caterpillar (*Malacosoma disstria*).

The average diameter growth on the axe-thinned plots has exceeded that on the control plots since thinning by 1.39 inches and presently has a volume in trees 5 inches d.b.h. and larger of 10.50 cords compared to 1.20 cords on the unthinned plots.

Let us assume that d.b.h. growth will continue at the same average rate as it has in the 12 years since thinning. Projecting the average growth of each individual tree on the thinned plots will give an average diameter of 6.3 inches in 6 years at age 25. A commercial clearcut could be made at that time yielding approximately 37 cords per acre. It would take the control plots considerably longer to approximate the same average diameter and cordage. We have thus significantly reduced the commercial rotation with the noncommercial thinning.

Although one study (Noreen 1968) questions the possibility of a net monetary return from precommercial thinning and another (Sorenson 1968) indicates poor diameter growth for crop trees in a thinned stand, it would seem from our study that more comprehensive research in noncommercial thinning is warranted if we want to reduce rotation or increase diameter.

## COMMERCIAL THINNING

In 1954 a commercial thinning experiment was established in two separate units known as Unit I and Unit II at different locations on our experimental forest. The stands on these units covered a total of 12.1 acres, were very similar, and had a site index of 85 to 90. The average age in Unit I was 31 years and the average age in Unit II was 34 years. Each unit was divided into three equal strips, one designated for clearcutting, one for partial cutting, and one for reserve as a control. Two 1/10th-acre permanent plots were established within each strip to measure results. All 12 plots were measured prior to treatment in the spring of 1954. The clear and partial cuts were made in the spring in Unit I and in the fall in Unit II.

The clearcuts removed an average of 50.3 cords and 124.57 square feet of basal area per acre and the partial cut removed about half the 593 stems and 27.86 cords from the total of 57.76 cords of volume (table 1).

The original plan in the partial cut areas was to thin from below to an approximate 13 by 13 foot spacing and 65 to 70 square feet of basal area. But it was found that a salvage of diseased or defective trees just about took care of the thinning with a basal area cut of 60.92 square feet and a final reserve of 69.99 square feet. Because the salvage of defective

trees did not always leave uniform spacing, a few openings larger than desired resulted. Unfortunately, some trees on the north side of these openings suffered sunscald.

The final clearcut was made in Unit II after the growing season in 1970 at 50 years of age; the scaled, cut volumes exceeded the plot volumes.

## Results

By 1970 aggregate volume in the partial-cut areas exceeded volume in the control by 17 cords, a net gain of 8.70 cords since 1954. The d.b.h. of the average tree in the partial-cut areas exceeded the average tree in the control by 1.73 inches. Net diameter growth in the partial cut exceeded that in the control by 1.45 inches.

## Veneer Potential Compared

In order to determine the veneer potential of the partial-cut areas compared to the control strips, veneer bolts on all plots were tabulated by size in 1969 (table 2). Bolts were then converted to finished veneer values (including residues) as reported by Noreen and Hughes (1968). It is evident that the partial cutting has had a marked influence on the size and value of veneer bolts.

Table 1. — *Plot data for aspen cutting study — average of two units*

	Per acre data <sup>1/</sup>			Average d.b.h. Inches	Age years
	Trees Number	Volume Cords	Basal area Square feet		
Clearcut strip (Fall 1954)	525	50.32	124.57	6.56	32.5
Partial-cut strip:					
Before cutting (1954) <sup>2/</sup>	592	57.76	141.39	6.77	32.0
Cutting	288	27.86	60.92	6.25	--
After cutting (1954)	252	29.52	69.99	7.43	32.5
Fall 1970	190	52.84	125.17	10.99	49.0
Cumulative yield		80.70			
Mean annual growth (49 years)		1.65		.23	
Reserve strip (control)					
At time of cutting	542	49.03	119.49	6.49	32.5
Fall 1970	318	63.65	148.66	9.26	49.0
Mean annual growth (49 years)		1.30		.19	

<sup>1/</sup> All volumes computed by formula on an individual tree basis.

<sup>2/</sup> The total of the trees and basal areas cut plus those remaining is not equal to those previous to cutting because of natural mortality and logging damage between initial measurement and measurement after cut.

Table 2.— *Veneer production for an uncut aspen stand compared to a partial-cut stand after 15½ growing seasons*

Top diameter (inches, inside bark)	Conversion return per bolt	Control		Partial cut	
		Bolts	Total value	Bolts	Total value
	Dollars	Number	Dollars	Number	Dollars
8	0.94	45	42.30	34	31.96
9	1.42	42	59.64	32	45.44
10	2.04	14	28.56	22	44.88
11	2.89	6	17.34	19	54.91
12	4.03	—	—	7	28.21
13	5.40	—	—	4	21.60
Total value on plots			147.84		227.00
Veneer value per acre			369.60		567.50
Total pulpwood value (at \$1.00/cd., 1954 and \$1.25/cd., 1969)			79.56		92.19

## Clearcut Strips

The first growing season following the 1954 clear-cutting the sucker counts showed an average of 15,950 stems per acre. This had been reduced by natural mortality to 1,825 stems in 1971.

In the fall of 1971 the average dominant tree had a d.b.h. of 3.21 inches and an average height of 36 feet so these stands are already well on the way toward the next crop and have a 17½ year average jump on the reserve and partially cut areas. Only time will tell whether an early clearcut is economically more advantageous for pulpwood production than a partial cut at the same age. This should prove a fertile field for studies by economists.

## COMBINING THE NONCOMMERCIAL THINNING WITH THE COMMERCIAL THINNING

If we are aiming for a saw-log or veneer market, what potential is theoretically possible if we combine a noncommercial thinning with a commercial thinning or partial cutting? We realize the many mensurational, biological, and climatic pitfalls involved in making straight growth projections based on the past average growth of individual trees especially when a year of practically no growth, due to the tent caterpillar, is injected into the averages.

Fully aware of the limitations involved, we made an adjusted projection based on the average past growth of individual trees in our sucker thinning and the growth information from our aspen commercial cutting experiment (1954-1970). Potential mortality trees (six of the largest trees on one plot, alive but infected with hypoxylon stem canker) in the present sucker stand were eliminated and growth projected by tree to age 32, with some adjustment for additional mortality based on this and other noncommercial thinning studies.

I then made a theoretical commercial partial cut reserving crop trees selected in the field on the two axe-thinned plots and simulating the partial cut in our 1954 aspen cutting study. In all, 385 trees with a volume of 36.15 cords were removed, reducing the stand to 74.28 square feet of basal area per acre (table 3).

The final projection based on growth of individual trees in our 1954-1970 partial-cut study was made to age 50 (table 4). The same experimental forest local volume table was used for all volume calculations.

This shows that our cultural measures have accomplished three things: increased the average stand d.b.h. by 4.53 inches, greatly increased the number of

Table 3. — *Results of theoretical management of an aspen sucker stand originally thinned at age 7 years and partially cut at age 32 years*

ACTUAL STAND

	Per acre data <sup>1/</sup>			Average d.b.h.	Age
	Trees	Volume	Basal area		
	Number	Cords	Square feet	Inches	Years
Spring 1960 (following thinning)	695	--	9.63	1.60	7
Fall 1971	675	10.50	86.61	4.84	19
PROJECTED STAND					
Projected to age 32 (Fall 1984)	550	57.75	198.81	8.13	32
Simulated cut, age 32 (Fall 1984)	385	36.15	124.53	7.70	32
Reserve, age 32 (Fall 1984)	165	21.60	74.28	9.08	32
Projected to age 50 (Fall 2002)	148	52.93	158.87	14.03	50
Cumulative yield (Fall 2002)	--	89.08	--	--	--

<sup>1/</sup> All volumes computed with an experimental forest local volume table.

Table 4. — *Stand table comparing a 50-year-old untreated stand with a theoretically managed stand on similar site (site index 85-90)*

D.b.h. : class <sup>1/</sup> : (inches)	Control stand			Managed stand		
	Total	Basal area	Volume <sup>2/</sup>	Total	Basal area	Volume <sup>2/</sup>
	trees	per acre	per acre	trees	per acre	per acre
	Number	Square feet	Cords	Number	Square feet	Cords
5	10	1.430	0.20	0	--	--
6	43	8.280	2.13	0	--	--
7	28	7.560	2.30	0	--	--
8	35	12.460	3.65	0	--	--
9	43	19.280	5.63	0	--	--
10	43	23.650	7.35	8	4.610	1.36
11	43	28.440	10.45	3	2.230	.66
12	38	28.910	9.38	13	10.620	3.25
13	10	9.470	2.95	29	26.038	8.99
14	5	5.200	1.80	52	57.293	18.87
15	--	--	--	27	34.479	11.52
16	3	3.540	2.40	9	12.314	4.32
17	--	--	--	4	6.164	2.16
18	--	--	--	3	5.126	1.80
Total	301	148.220	48.24	148	158.874	52.93
Average basal area		.492			1.073	
Average d.b.h.		9.50			14.03	

<sup>1/</sup> Trees 5 inches and larger.

<sup>2/</sup> All volumes computed with a local volume table believed to be conservative.

stems in the larger diameters, and increased the total cumulative yield by more than 40 cords (theoretical thinning at 32 years, 36.15 cords, plus final projected volume of 52.93 cords). While there may be some question concerning such a large comparative increase in cumulative cordage, there is little question that significant increases in diameter can be accomplished by such management practices.

## CONCLUSION

These comparative noncommercial and commercial thinnings and those carried on by others (Day in Upper Michigan, Steneker and Jarvis in Manitoba, and Zasada on the Chippewa National Forest in Minnesota) have shown that, *under the right conditions*, aspen has excellent management potential, especially if the aim is to supply a saw-log or veneer market. Because of its suckering ability, there are no planting or release costs and the larger average diameters should reduce logging costs. Thus for stands close to the mill more intensive culture is within the

realm of economic feasibility. Government agencies with a subsidized labor force, should carefully consider more intensive management of aspen because the day of aspen surpluses, especially of saw-log or veneer size and quality, is rapidly drawing to a close.

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# MECHANIZED HARVESTING SYSTEMS CAN AID MANAGEMENT

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**ABSTRACT.**—Mechanized timber harvesting systems in the Lake States show promise for increasing labor productivity and improving utilization of the resource. These systems can be used in the aspen type for sustained timber and wildlife production with little impact on soils and scenic values.

Mechanization has changed aspen timber harvesting in the Lake States during the last 10 years. The systems now under development have good potential for increasing efficiency of timber harvesting; the products may be removed as short logs, tree-length material, full trees, or chips. These new systems offer several advantages, including higher labor productivity, less manual work, and improved utilization of the timber resource. At present they are used most successfully in clearcutting even-aged stands.

Because of public concern about the environment, acceptable mechanical harvesting systems on public lands must meet certain multiple-use requirements. The Cloquet Forestry Center has studied the effect of mechanized harvesting on the aspen forest. The results of this research indicate that properly directed mechanized harvesting can aid in the management of the aspen type for sustained timber and wildlife production with little impact on soils and scenic values.

## AREA AND CONDITIONS OF ASPEN TYPE TO BE HARVESTED

About 65,000 acres of aspen type have been harvested annually in northern Minnesota during the past 5 years. This is about 1½ percent of the type on medium and better sites. The harvested stands are usually more than 40 years old with trees in the 6- to 15-inch diameter range. Aspen occurs in five general condition classes as follows: (1) pure aspen, (2) aspen-birch mixture, (3) aspen-conifer mixture, (4) aspen-northern hardwood mixture, and (5) understocked stands with brush.

Because of increasing use of aspen, it is expected that at least three-fourths of a million acres of this type will be logged in the next 10 years. The merchantable stands available for harvesting will be similar to those now being cut. The 1962 forest survey showed that 35 percent of the type was in the 40+ age class, and an additional 48 percent was in the 20 to 39 age class. How these stands are harvested will determine the quality of the next aspen timber crop as well as the potential for wildlife habitat.

## MANAGEMENT OBJECTIVES

A good distribution of age classes and full stocking of pure aspen stands on medium and good sites must be provided to meet the demands for aspen forest products and the requirements for wildlife habitat. Aspects of aspen silviculture that must be considered at harvest time to meet this objective include site quality, reproduction, habitat improvement, soil protection, stand development and protection, and length of rotation.

Recognition of site quality would make it possible to determine which areas are not suitable for either commercial wood production or habitat development. Stands on poor and medium sites would be harvested when they reach pulpwood size. On good sites, stands would not be harvested prematurely—they would be grown to produce the high-value products such as veneer and large saw logs of which they are capable. This approach will result in less loss through mortality and overmaturity, limit natural stand conversion, and provide more good wildlife habitat areas.

A complete clearcut is necessary for good aspen reproduction. It also reduces invasion by tolerant species that produce little usable volume and eventually allow complete conversion of the stand. Scenic values and wildlife needs may require limiting the size and dispersal of areas to be clearcut.

## DEVELOPMENT OF STANDS SUITABLE FOR MACHINE HARVESTING

Pure stands of aspen have many characteristics that favor profitable mechanized harvesting; they are even-aged, contain a high volume per acre, and most important, the trees fall within a limited diameter range. In addition, most aspen forests occur on sites that permit year-round harvesting.

Stands of sucker origin following clearcutting can be better stocked and possess equal or better vigor than the original stand. Rapid growth and natural thinning are characteristic of such stands; trees will attain a height of 4 to 6 feet and number more than 7,500 stems per acre the first year. At age 10, the trees will be 25 feet tall and number 3,000 stems per acre. By age 20, further natural thinning will reduce the number of stems to about 1,700 per acre, and the trees will be 40 feet tall. The young stands show no tendency to stagnate because of heavy stocking. Individual tree dominance is pronounced. Good stand growth is maintained even without thinnings.

Because of uniform spacing and a common starting time, pure, well-stocked aspen stands contain a large number of trees fairly close to the same diameter. For example, at age 11 about 90 percent of the stand will be in the 1- to 2-inch size class; at age 20 about 80 percent will be in the 2- to 4-inch class; and at age 55 about 90 percent will be in the merchantable size class of 6 to 10 inches.

Recent proposals have been made for growing and harvesting tree crops using a very short rotation. A "Sycamore Silage" approach has been proposed by Herrick and Brown in the South. In Wisconsin, Einspahr and Benson suggest a similar approach for aspen. The limited range in diameters at given ages indicates that short rotations may be possible in aspen provided the stands are kept free of competition.

Aspen stands reach maturity when they are from 40 to 60 years old, earlier on poor than on good sites.

Thereafter they open up as a result of decay or damage from ice and wind. Mature and overmature stands are invaded by brush and more tolerant hardwoods that usually reduce the quality of the next stand. Because aspen is a forest type that deteriorates rapidly after reaching maturity, harvesting at rotation age is necessary.

## HARVESTING SYSTEMS IN USE

Three harvesting systems are used in the aspen type in northern Minnesota. The *shortwood system* is the conventional, most widely used method of logging, with felling, limbing, and bucking done at the stump and logs skidded or forwarded to haul roads. Although machines have been developed for full mechanization of this system, most small operators fell the trees with chain saws. Skidding is done with one of several types of forwarders equipped with power loaders.

In the *tree-length system*, trees are felled and limbed at the stump. Tree-length logs are skidded to a landing, where they are processed into logs or moved directly to the mill. This system is gaining in use due to the success of the rubber-tired skidder, which makes high-speed, long-distance skidding possible. The number of skidders used in northern Minnesota has increased from about 100 machines in 1965 to more than 1,000 during the 1970-71 logging season. The trend of mills toward equipping their yards to accept and handle tree-length wood will promote further expansion of this system.

The *full-tree system* has been used to a limited extent in harvesting aspen. With this system the only work done at the stump is to fell the tree. The full tree is skidded to the landing for limbing and processing into logs. Machines such as a feller-buncher and tree processors also are available to fully mechanize the operation. As practiced by most operators, the system is partially mechanized with felling done manually.

These systems offer to the forest land manager three alternatives of removing the forest crop: (1) as logs, leaving cull logs, branches and tops in the forest; (2) as tree-length logs (or polewood), leaving only branches and tops in the forest; and (3) as full trees, leaving no residue in the forest.

## EFFECT OF HARVESTING ON THE FOREST

The condition of the area following logging determines the treatments necessary to establish desirable forest reproduction, reduce soil erosion, and provide acceptable wildlife habitat and esthetic conditions. Residual conditions resulting from the three harvesting systems—slash cover, impact on soils, disturbance of the shrub understory, and damage to residual trees—were examined on commercial logging operations. The utilization of aspen was complete by current market standards. All merchantable aspen trees 6 inches in diameter and larger were cut for pulpwood. Because of variations in market contracts among operators, merchantable trees of other species were not taken on all the study areas. No special requirements were imposed on operators. Thus, the condition of these cutover areas probably are typical.

### Damage to Residual Stand

Where aspen is managed for continuous timber production, the harvest cutting should remove the total stand—merchantable trees, nonmerchantable trees, and even advanced reproduction. Previous studies and observations show that the completeness of the clearcut varies with stand conditions and the degree of utilization of aspen and associated species. The harvesting system used and degree of mechanization involved also have a great impact on the condition of the site after logging.

A comparison of the three harvesting systems using manual felling and machine skidding shows that the tree-length and full-tree systems eliminate more of the residual trees than the shortwood system. A strip-cutting pattern with shortwood logs bunched on or along a skidroad confines the skidding activity to a limited area, whereas moving full trees or tree-length logs distributes skidding effects randomly over the area.

Fully mechanized operations result in a more complete clearcut than partially mechanized operations. Where machine felling was used, 90 percent of the nonmerchantable trees 1 inch in diameter and larger were eliminated to facilitate harvesting of the merchantable trees. In manual felling, only 65 percent were eliminated; although some were knocked down in the skidding operation, the cutters found it more efficient to walk around the nonmerchantable trees.

The three fully mechanized harvesting systems were equally effective in eliminating the residual nonmerchantable trees.

Although fully mechanized operations do the best job of residual stand removal, during the next 10 years the partially mechanized tree-length system probably will be more widely used to move tree-length aspen timber from stump to landing. This system eliminates 50 percent or more of the residual stand and advance reproduction, but still does not accomplish the full stand removal needed in aspen management. A survey of 1,700 acres of aspen type in Hubbard County harvested by this method showed good reproduction—7,000+ stems per acre 3 years after logging. However, the survey also showed that 26 percent of the poor-site plots and 41 percent of the good-site plots were stocked with tolerant hardwoods 1 inch in diameter and larger.

The effect of leaving this residual stand free to grow was shown by a study in the Pike Bay Experimental Forest in Cass County, Minnesota. A well-stocked stand of aspen that was established after clearcutting was thinned at age 13, and the invading tolerant hardwoods were removed. An untreated check area was left for comparison. Thirty-five years later, at age 48, all the volume in the treated area was in aspen. In contrast, only 71 percent of the volume in the untreated check area was in aspen; the rest was in hardwoods that were generally inferior in value and quality.

It is suggested that pilot plant trials be conducted now to determine the feasibility of requiring the removal of this residual material as part of the harvesting operation.

### Ground and Understory Disturbance

The use of heavy machines in the forest has raised concern about their effect on soils and understory vegetation. The degree of disturbance observed in these logging operations was described by the following classes:

*None.*—No disturbance to soil or shrubs.

*Light.*—Wheel tracks of machine visible, no mineral soil exposed, litter layer packed. Brush layer broken down or bent. Machine usually traveled on

area only once in skidding full trees or tree-length logs.

*Medium.*—Wheels or logs broke through litter layer, mineral soil exposed, compacted. Shrubs broken down or uprooted. Machine may have traveled on same trail several times. Wheels did not break into root mat.

*Heavy.*—Same as medium, except area used several times as a main skidding trail for long skidding distances, often resulting in deep ruts and severing of roots to a depth of 4 inches or more. This situation can develop with only few trips when the soil is wet.

The greatest disturbance resulted from use of the full-tree system and summer logging (table 1). Machine activity increased the soil bulk density in the heavy and medium disturbance classes; this occurred on 35 and 45 percent of the tree-length and full-tree areas respectively, and 25 percent of the shortwood area. Medium and heavy disturbance occurred about 35 percent less often on winter-logged areas than on summer-logged areas.

Table 1.—*Understory and ground disturbance by harvesting system, in percent of area disturbed*

Harvesting system	Disturbance class			
	None	Light	Medium	Heavy
Shortwood	51	26	15	8
Tree length	34	28	29	9
Full tree	24	30	35	11

Aspen reproduction became established immediately after logging except where heavy disturbance occurred. Fall- and winter-logged areas were stocked the following summer. Spring- and summer-logged areas were stocked by fall. Only scattered trees and grasses became established on the heavily disturbed areas.

These measurements indicate that heavy disturbance of an area may limit regeneration and accelerate erosion on steep slopes. No such adverse effects have actually been observed, however, possibly because this disturbance class makes up less than 10 percent of the area and occurs in scattered small patches.

Aspen silviculture and wildlife habitat improvement guides recommend heavy disturbance of the shrub understory stands during the logging operation

for successful aspen regeneration and browse production. The largest amount of shrub uprooting and density reduction results from use of the full-tree system followed in order by the tree-length and the shortwood system. However, if an effort was made to distribute the skidding activity over more area, equal amounts of brush disturbance could result from all three harvesting systems.

## Slash Cover

About a third of the area harvested by the shortwood and tree-length systems was covered with slash from limbing and topping trees; however, the slash patterns were different. On the shortwood area the slash was arranged in continuous rows parallel to the cutting strip; on the tree-length area it occurred in randomly scattered piles. Where full-tree logging was used, slash covered less than 10 percent of the area and was concentrated so it could be safely disposed of by burning or chipping.

Slash from clearcutting aspen does not prevent establishment of a fully stocked stand of reproduction by suckering. In fact, the three harvesting systems are equally acceptable for stand establishment. Other multiple-use benefits such as scenic values and wildlife habitat improvement, and the need for prescribed burning or hazard removal should be considered when making a choice of aspen harvesting systems.

## COST COMPARISON

Few data are available for comparing the costs of aspen harvesting systems. The limited information gathered in our studies shows that the costs for full mechanization are higher than for partial mechanization at current machine and labor rates. However, production rates per hour are much higher with full mechanization.

One study compared production rates and determined silvicultural impacts of four mechanized harvesting methods that might be used by a small operator. The study stand was 50 years old and had a volume of 18 cords per acre with eight trees per cord. Harvesting cost per tree (stump to landing) varied from 34 cents with manual felling and limbing with tree-length skidding to 40 cents with machine felling and bunching with full-tree skidding and manual limbing. The highest production rate—31 trees per hour—and the best residual stand conditions for

aspen land management were achieved with full mechanization. The area was free of slash, shrub disturbance was heavy, and few residual trees remained.

The additional cost that will result from including silvicultural treatments in the harvesting operation needs further study. Available information indicates that for stands under 55 years of age, including this requirement will have little impact on production cost. Most of the residual trees are small and at least half are destroyed when removing the merchantable crop.

### Size of Area

A limitation on size of clearcut is recommended by game biologists and landscape planners to meet the requirements of wildlife habitat and forest esthetics. There is no information on the size of current cutting areas but there are several indications that most are fairly small:

1. About 50 percent of the timber cut annually is produced by small operators, many who log only part time.

2. The large number of sale permits issued by public forestry agencies indicates that cutting is done on small areas. In 1967 and 1968 these agencies issued 626 and 617 permits in Itasca County, and 469 and 446 in Beltrami County.

3. Large timber producers who have fully mechanized operations will log areas with volumes of 500 to 1,000 cords. Such volumes can be harvested from well-stocked stands on 20 to 40 acres.

4. The scattered landownership pattern and variable land conditions of soils, swamps, and topography lessen the chances for large cutting units.

It is possible that most individual timber sales now meet the area recommendations of game biologists — 20- to 40-acre cutting units. Large clearcut areas often result, however, where a number of small sales are located next to each other. Better coordination of harvesting among large forest landowners may permit meeting the multiple-use needs of aspen land management.

The potential impact of mechanized harvesting on long-range aspen management should be recognized

in future planning. Even the small operator can become a large producer because a two-man crew can harvest more than 100 cords per week. As mechanized harvesting becomes the common practice, careful planning will be necessary to meet both the objectives of efficient year-round timber production and aspen land management.

### SUMMARY

1. In the next decade up to three-fourths of a million acres of aspen stands age 40 years and older will be harvested in northern Minnesota. How this area is logged will influence both the future management costs and the quality and yield of timber and wildlife. Silvicultural requirements for aspen based on research and experience are available to guide the harvesting program.

2. Mechanization has changed harvesting methods in aspen. It has provided ways of removing the forest crop that will result in residual forest conditions favorable to aspen land management.

3. As currently applied, mechanized harvesting has little adverse impact on forest soils or watershed conditions.

4. Mechanized harvesting has the potential of removing nonmerchantable trees and disturbing the shrub understories (requirements for stand establishment and growth and for wildlife habitat improvement) as part of the logging operation.

5. Pilot-plant tests are needed to determine the costs and stand conditions under which silvicultural, wildlife habitat, and esthetic requirements can be included in the logging operation. Similar tests are needed to determine methods of adapting size of clearcut to meet both land management needs and timber production requirements.

6. Good aspen silviculture can provide the stand structure and conditions necessary for efficient use of mechanized harvesting, as shown in the following tabulation:

<i>Conditions best for machine performance</i>	<i>Silvicultural conditions for aspen management</i>
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Clearcutting.

Complete clearcut best for regeneration and stand development.

Harvesting one product and one species.	Pure stands grow best and produce highest yields.
Uniform size.	Rapid natural thinning maintains a limited diameter range through the rotation.
Large number of trees per acre and uniform stocking.	Pure aspen stands tend to be fully stocked.
Year-round logging chance.	Aspen grows on upland sites suitable for year-round logging.

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# MANAGEMENT AND THE FOREST INDUSTRY

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**ABSTRACT.**— The forest industry of the Lake States is vitally concerned with the future of the aspen forest. Use of this resource is increasing significantly. Industry has three major concerns regarding the utilization of aspen: (1) the resource supply data is old and out of phase with demand projections being made; (2) a number of problems must be resolved in timber management and harvest; and (3) a balanced plan of multiple-use management for the aspen cover type is needed.

## SUPPLY AND DEMAND

To state that the forest industries located within the geographical boundaries covered by this symposium are interested in the aspen resource would be a gross understatement. Recent trends in the utilization of this resource and projected future consumption levels firmly establish industry's commitment to and dependence on the aspen species. A great deal has been written regarding the aspen supply and demand situation for this symposium and will continue to be a subject of primary importance to industry in the future. Many statistics have been presented and analyzed by those more qualified than this author. Thus, I choose not to belabor this point, but merely wish to bring forth a few figures to reaffirm our position.

During the period 1946 to 1970, pulpwood production in the Lake States, including all species, increased from 2¼ million cords to over 4¼ million cords. During this same period, the aspen harvest alone increased from 713,000 cords to 1,967,000 cords. The aspen volume percentage of all species harvested increased from 32 percent in 1946 to 46 percent in 1970.<sup>1</sup> The pulpwood production levels should serve as an adequate guide as it appears from analysis of resource consumption reports that pulpwood comprises roughly 75 percent of the market. This brief analysis indicates that the growth in use of aspen has been significant.

How does industry view the future aspen supply-demand situation? This is probably one of the most frustrating problems continually facing the respective company woodlands departments. Market conditions may indicate the advisability of significant capital investment in plant and equipment for the production of aspen-based products. The question is then tossed to woodlands managers for an analysis of the long range resource supply situation. The traditional routine of examining allowable cuts, current harvest levels and estimating surpluses within the supply area of interest then begins. Unfortunately, a report finally goes back to management with estimated resource statistics carrying a plus or minus 50 percent factor for unknowns. I am encouraged by the papers presented at this session which indicate the possibility of more sophisticated methods that may be applied to this subject of resource availability and should eventually result in more accurate projections.

In the interim, however, we are faced with the current dilemma of dealing with estimates based on data containing many unanswered questions. Aspen inventory and allowable cut data is old and extremely difficult to utilize. It has, to date, been a poor base for the investment values which are dependent upon this information. Current estimated aspen surpluses look inviting to production people and the general public in their observations of the forest resource. However, I find an increasing number of resource analysts reducing their estimates by 20 percent to 50 percent based on unknowns apparent in the data. Again, I feel that the new forest surveys and revolutionary data processing techniques will greatly improve this situation in the future.

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<sup>1</sup> *Reports of pulpwood production published by the North Central (formerly Lake States) Forest Experiment Station from 1948 to 1971.*

Realizing the hazards mentioned above, in September of 1970 I attempted to project future aspen consumption levels for the Lake States. A group of wildlife managers were interested in this same subject. The analysis at that time indicated that the forest industries of the Lake States would be rapidly closing the gap on present estimates of aspen surpluses by 1980. These observations were, of course, made from existing forest inventories and based on current levels of aspen management. At this point, almost 2 years later, aspen use is growing and the projection of nearly complete use of the aspen resource within the next decade seems within reason. It also seems reasonable to assume that aspen utilization will remain strong as long as it continues to be a significant component of our forest types.

A few brief comments regarding the reasons for industry's increased interest in the aspen resource are probably in order. Aspen was elevated from its "weed tree" status in recent years due to advanced technology in its utilization and its increasing availability over the past twenty years. Research resulting in improved harvesting, processing, pulping, and milling methods has proven that aspen contains chemical and physical properties desirable to the manufacture of quality forest products in this region. The occurrence of aspen in relatively uniform and pure stands makes it a desirable species from a logging cost viewpoint. Its favorable growth rate, short rotation, and ease of regeneration on a range of forest sites usually results in a favorable forest management analysis. The manipulation of the aspen type has proven to be of significant value to deer and grouse populations of the Lake States. Thus, the aspen resource is a versatile forest cover type which responds favorably to multiple-use forest management objectives as well as having a ranking position in the forest products raw material supply picture.

## MANAGEMENT AND HARVEST

If we now agree that aspen is of major importance to the future of the Lake States forest economy, let us look briefly at some of its timber management problems as they relate to the consuming industry. I doubt that there are many involved with the symposium that would dispute the fact that aspen at rotation age must be harvested by clearcutting. Intensive research has proven that this practice is ecologically sound and must be used if the aspen type is to be maintained at its highest level of productivity. This

proven silvicultural system is attractive to loggers because it makes mechanized harvesting economical and efficient. Yet, one of the greatest threats to the future potential of the aspen forest is by well-meaning but poorly informed concerned conservationists who would terminate this required even-aged management practice. It is evident that industry is probably most concerned about the long range effect of such a threat should it materialize due to its potential catastrophic setback to the aspen supply picture. Everyone interested in the future of the aspen forest resource should promote the merits of properly applied even-aged management and its long-range multiple-use benefits.

Several other problems concern industry in the management and harvest of the aspen type. Most of these occur in the contracts for sale of aspen timber by public agencies upon which the Lake States forest industry is highly dependent. I would not question the intent of the objectives outlined in sale contracts for improvement in the quality of the new aspen forest which will follow the harvest; however, the methods remain of concern. Stand improvement techniques carried out as part of the timber sale, such as residual stem removal, slash distribution and management, and access road construction, are in need of clarification insofar as the cost of logging is concerned. Contracts indicate that such requirements are allowed for in the determination of stumpage rates. It is apparent, however, that considerable additional work must be done to more accurately identify the costs involved to the logger. Also, it may be advisable to accomplish many of these items on a post sale treatment contract that is completely removed from the harvesting operation. Whichever system is used, the costs must be accurately identified.

In aspen management, industry is obligated to do an efficient job of harvesting and utilization. Over the last decade, important advances have been made. Increased demand for aspen has resulted in a much more complete job of utilization in the 1970's than was ever envisioned in the 1950's. The development of mechanized harvesting by loggers has resulted in a much better job of harvesting. There is still room for improvement and the outlook indicates that progress will continue at an accelerated rate with the construction of additional aspen-consuming facilities. The advent of the metro-harvesting system utilizing all trees to a 2-inch d.b.h. class is an example of recent developments.

The public land agencies also have an obligation to facilitate efficient harvesting. Some advances have been made, such as area estimate sales, acceptance of weight scaling, and consumer scale. However, the logger feels that more improvement can be made. Many requirements are added to the contract without any advance discussion with him and without any test or study to determine what impact these requirements will have upon the logging operation.

If we consider that proper harvesting of the crop is the most important forest land management practice in managing aspen, then the key man in aspen management is the logger. The success of the harvest and renewal of the stand is essentially in his hands. He must be considered a partner to the forest manager in accomplishing the management objectives for aspen or any other forest cover type. He should become a part of the decision-making process in developing contract conditions. A logger who understands the long range objectives of the harvesting plan through continuous field contact by management personnel will in the majority of cases respond favorably and go that extra step to comply. The logger of today is generally a cost-conscious businessman and vitally concerned with the continuous yield of the forest for his livelihood. He is an integral part of the management process and not a separate step to be considered as a necessary evil. A mutual understanding of problems will be a major step toward better silviculture and utilization of the aspen resource.

## MANAGEMENT AND MULTIPLE USE

Industry is concerned with several multiple use benefits other than timber from the aspen forest. The current concern for more attention to wildlife, esthetics, watershed protection, soil disturbance and recreation values in the management and harvest of aspen is substantial and growing daily. Improvements and changes in procedures are, no doubt, needed in management practices. However, past aspen management plans need not be apologized for because they have been, for the most part, in line with economic conditions, markets, and most public needs. Current environmental interest has now brought forth a number of new concerns that must be considered in the plan of management. Most of these concerns focus on the harvesting operation and will result in additional logging costs of varying degrees.

Manipulation of the aspen type is showing increasing potential in the management of the Lake States' major game species, deer and grouse. Habitat improvement has been realized for many years from almost every aspen harvesting operation. Benefits such as increased browse, openings, stand edges, and variable stand age classes have been an indirect result of harvesting operations and of major value to wildlife populations. This has all been accomplished by logging at no additional cost to wildlife management. In turn there has been no special design in the timber sale for wildlife management and general logging costs have not been affected. Recent proposals indicate that aspen timber sales should be planned for specific objectives in wildlife management. Items such as size of harvest area, pattern of cutting, distribution of openings and edges, and residual cover areas are a few examples.

Research and management experience has indicated that these changes in harvesting patterns may be desirable and we will want to include some of these objectives in future sale designs to a practical degree. However, many of these changes will result in increased logging costs due to required changes in operating methods. This additional cost should not be borne by timber management budgets and loggers alone. Many others will benefit from these improved techniques and should share in the costs involved. Also, at this point in time the wildlife management guidelines have not been firmly established. Before they become contractual requirements, they should be evaluated as to impact on production costs and the logger should participate in these decisions.

The esthetics of aspen harvesting is of major current interest. Objections arise daily to the appearance of areas following harvest. I believe we would all basically agree that there is no visual appeal to an area immediately after logging. However, the appearance does not usually relate to the quality of aspen management. Esthetic improvement beyond standard slash disposal and orderly logging requirements are additional costs for benefits received other than economically sound forest management. Changes in logging requirements and resulting costs which include size limitations of cutting area, slash disposal requirements to reduce visual impact, landscaped cuttings, and reserve screens must be recognized for their esthetic value and not solely as a cost of timber management.

This same analysis would apply to other multiple-use values of the aspen forest. Many of the suggested changes directing more attention to values other than timber are meaningful and desirable. However, these additional management costs must be evaluated and assessed to the respective benefit desired. Timber management and logging cannot absorb these costs alone. The other amenities to be improved through aspen management must carry their share of the load.

As a final note regarding multiple use of the aspen type, I would like to make a special plea to all agencies concerned with research and management. It is easiest when pressure is mounting for attention to a particular facet of management, to pursue this item in the name of progress. We are in need of better balance in striving for improved multiple-use management. In a hit-and-run approach to a specific problem, we may often be tipping the scale farther rather than heading toward a desirable level. There is a real need for the forest manager to draw together the best techniques from all disciplines concerned in an attempt to develop a balanced plan of management for the aspen forest. Such a balanced management plan will be practical and will result in realistic cost-benefit ratios.

## SUMMARY

In summary, the forest industry of the Lake States is dependent upon and consequently vitally concerned about our aspen forest. We strongly endorse the research and management studies devoted to aspen which are presented in this symposium. The studies related to the supply and economics of the species will assist industry by providing more reliable data for potential expansion estimates. Utilization studies will be of significance as the demand for more complete use of this resource continues to grow. Additional contributions through genetics, silviculture, ecology, and protection research will be of increasing value to the forest manager. Finally, research efforts in the related use fields will assist in keeping us on the right track insofar as balanced use of the forest is concerned.

I have referred to some problems that are of concern to the forest industry regarding the supply, demand, management, and harvest of the aspen forest. However, it is my firm belief that the exchange resulting from this symposium will contribute significantly toward realization of the full productive potential of this key Lake States' forest resource.

# MANAGEMENT ON THE NATIONAL FORESTS OF THE LAKE STATES

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and  
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**ABSTRACT.**—Aspen is managed on the National Forests to meet multiple-use goals. Consideration is given to aspen timber commodity values, other timber species commodity values, wildlife habitat, esthetics, and environmental protection. We have three broad options in treatments; regenerate aspen, allow natural conversion to another type, or artificially reforest with conifers. The choice of treatment depends on multiple-use objectives and local ecological conditions.

If there is a Cinderella among our eastern tree species, aspen is very likely it. A few years ago aspen was a despised weed tree and aspen stands were converted to stands of other species as soon as practicable. Now aspen is important in meeting the management objectives of our National Forests. Aspen has been able to establish itself and to prosper under conditions adverse for tree growth. Meanwhile, new utilization techniques have made it one of the most important tree species in the Lake States.

## EXTENT AND UTILIZATION

The aspen-birch type covers 1.7 million acres or 30 percent of the commercial forest land on the National Forests of the Lake States. Aspen volume, according to our most recent timber inventory estimates, totals 880 million cubic feet. This is about 21 percent of the total commercial timber volume on the Lake States National Forests.

The present annual allowable cut is 51,000 acres. The estimated volume of aspen that should be harvested annually in all timber types is about 41 million cubic feet or slightly less than 5 percent of the total growing stock volume. Aspen is relatively well utilized on all our forests except for the vast reserve of aspen on the Superior National Forest. If we consider only the other Lake States forests, we find the area of actual regeneration cut is about 80 percent of the allowable.

The portion of aspen in the total volume of all species cut has remained remarkably stable at about 38 percent for over 15 years. During this time the harvest volume of aspen has increased from 220,000 cords to 275,000 cords annually (includes a minor amount of paper birch).

Stumpage prices received recently for aspen vary from our minimum rates of 50 cents per cord up to \$5.00 per cord. The higher rates are received on parts of the Nicolet National Forest.

## MANAGEMENT OBJECTIVES

As you know, it is important to keep the Forest Service in tune with the changing world in which we live. Making sure that we are responsive and alert to the changing needs of a dynamic society requires a continuing evaluation of our management objectives and policies.

In order to meet this need, the Forest Service has developed a new framework to help guide our thinking and decision-making throughout the Service. This guide is entitled "Framework for the Future." It is the result of much thought and discussion and I commend it to your attention. The objectives and policy statements identify the general scope and character of the role the Forest Service should play in the society of today and tomorrow. I mention this because its direction and timeliness is part and parcel of this new era in aspen management.

Some broad new objectives that we must consider in managing our aspen are:

- To promote and achieve a pattern of natural resource uses that will best meet the needs of people now and in the future.

- To protect and improve the quality of air, water, soil, and natural beauty.

- To generate forestry-based job opportunities to accelerate rural community growth.

- To encourage the growth and development of forestry-based enterprises that readily respond to consumers' changing needs.

- To develop and make available a firm scientific base for the advancement of forestry.

In order to meet these broad objectives, we have changed our concepts of aspen management. No longer do we confine our thinking to wood production alone. We must fit aspen lands into the total resource and environmental picture. We have considerations that change or modify strictly timber production options. Moreover, a choice of action is not based on simple rules and it cannot be made for any single stand of timber in isolation from the surrounding land and human developments.

### **Timber, Wildlife, Fire, and Environmental Objectives**

Both the wildlife and timber commodity values of aspen are important factors in management. But, because these subjects are examined in great depth by others at this Symposium we will only mention them briefly here.

Certainly, we must continue to consider the national need for timber which clearly calls for the intensification of management for conifer sawtimber, including the conversion of aspen to conifers. And, we will consider local industry needs for a continuing aspen wood supply.

Aspen is extremely important for the maintenance of good wildlife habitat. The total area in aspen, the mixture of age classes, and the spatial relationship of aspen stands with stands of other species are all im-

portant habitat factors. So size of area harvested, shape of the area, and distribution of the harvest areas must be considered in managing aspen stands. Of equal importance for wildlife are decisions regarding conversion of the type to conifers or northern hardwoods.

Fire protection is also a consideration in aspen management. In large areas of pine, strips of hardwoods are desirable for fuel breaks and for fire fighting purposes. Aspen may be regenerated for this purpose even though the soil is more suitable for pine. Separating pine stands with aspen strips also dovetails with wildlife and esthetic needs for diversity in conifer areas.

Environmental protection, of course, is paramount. Therefore, soil, air, and water protection needs may influence management decisions for aspen stands.

### **Esthetic Objectives**

The esthetic values of scenic areas, heavily used recreation areas, and travel corridors need to be protected. In these areas we are particularly concerned with the appearance of timber treatments. High contrasts in form, line, color, and texture, such as occur in a poorly designed aspen regeneration cut, have a negative visual impact. With skillful planning, the visual impact of cuts need not be shocking. Size, shape, distribution of cutting units, topography, vegetation, and viewing distance can all be used to minimize contrast and maximize continuity in the landscape.

The size of an aspen clearcut largely determines its visual impact. Normally, small cuttings are preferred; a number of them made at different times can provide a variety of age classes. But simply setting a single upper size limit on cuts is not the answer. Resource values, deviations from the surrounding or characteristic landscape, and the apparent size created by the viewing distance, must all be considered. The appearance of even large cuts can be improved by leaving trees standing near natural features such as boulders, rock outcrops, hills, ponds, and marshes; the apparent size of cuts can be reduced by restricting the viewing distance.

An aspen clearcut can be shaped to blend in with the characteristic landscape. Straight cutting lines, strips, or rectangular blocks should be avoided in

favor of free-form shapes that follow natural projections, indentations, and soil and topographic features, thus exposing smaller areas of clearcut to view. Irregularity and variety in clearcuts are not only esthetically pleasing but can also be ecologically sound for natural plant communities.

Proper timing and dispersal help improve the appearance of clearcuts. Sufficient time should elapse between successive cuts on nearby areas. But the same spacing and timing guidelines cannot be used in all cases. Topography, forest type, stand conditions, soils, and other factors must be weighed in each situation.

Along selected roadsides aspen stands should be managed to maintain appropriate species in good health and provide beauty and variety. Silvicultural treatments used may include planting, thinnings, removals to provide vistas, conversion to other vegetation types, and leaving clumps of birch or spruce to frame vistas. Aspen itself lends richness to the landscape because of its colorful spring and fall foliage and its light bark.

Logging residue and slash should be promptly removed from roadsides, which act, in effect, as display windows. Logging slash along roads or trails, even though it is soon decayed, leaves a lasting, unfavorable impression on the public.

## **TREATMENT OPTIONS**

We consider aspen to be an extremely "pliable" type in that several management options are feasible depending on multiple-use objectives and the ecological conditions of the area under consideration. Aspen is found on a wide range of soil conditions and can be associated with virtually every other species that grows in the Lake States. There are generally three broad management options for aspen stands: (1) maintain the aspen type through regeneration cutting, (2) convert naturally to another timber type that is ecologically higher in the successional ladder through partial cutting or by no cutting, and (3) artificially reforest other species by planting or seeding.

### **Maintaining Aspen**

We manage pure aspen stands under the even-aged system of silviculture. There is no provision for thin-

nings in immature stands. Our aspen is considered mature when it is pathologically mature or at 40 to 50 years of age, whichever comes sooner; and allowable cut is usually based on about a 45-year rotation. We depend primarily on reproduction from root suckers of the cut aspen stems. We also obtain some seedling reproduction where mineral soil is exposed. If more than 15 percent crown cover remains after commercial harvest we consider an investment in residual tree removal. An investment of this type is generally not justified on an economic return basis for stumpage alone. We justify treatment on the combined values for wildlife, timber, and esthetics.

Some portions of aspen stands may be retained beyond rotation age or regenerated before they are mature in order to increase the spread of age classes in local areas. The aim is to obtain a normal distribution of age classes that benefits wildlife, maintains an even flow of timber products, and improves the characteristic landscape.

## **Natural Conversion To Other Types**

The soil and the species mix of the stand are the primary considerations in determining the course of action. Management simply assists natural ecological succession toward the climax type on suitable soils. For instance, northern hardwoods often occur as an understory in aspen stands. If stocking of desirable hardwood stems is adequate and the site is well suited to hardwoods, we generally will manage for the hardwoods. The economic justification is not always clear, but we normally favor working with the natural vegetation and this swings us toward favoring the development of the more stable northern hardwood succession. However, even here such a stand may be regenerated to aspen for wildlife purposes or for timber production. Often there is a good mixture of paper birch with the aspen. In some of these cases we should manage for the birch, particularly on the more productive sites or where esthetic benefits are involved. Another common mixture is aspen with a balsam fir-spruce understory. The easiest course in such instances is merely to cut the aspen and obtain a mixed stand of fir, spruce, and aspen.

### **Reforesting Aspen Stands With Conifers**

The term "conversion" is commonly used when pine or spruce are planted on an aspen regeneration

area. However, "conversion" is loosely used and may not be strictly true because we are usually restocking the area with species that originally grew there and are gone because of repeated fires after the virgin timber was logged.

Much of the aspen is on well-drained sandy soils that formerly supported the pines. On these areas we consider reforestation with pine rather than regenerating another stand of aspen. Economic analyses will usually indicate a favorable return in reforestation with conifers. It is also desirable in light of long-term outlook for needed conifer sawtimber. However, more immediate needs for wildlife habitat often outweigh the timber consumption considerations in deciding to maintain aspen on pine lands. To a more limited degree, fire protection and water yield considerations favor aspen management on a portion of the pine lands.

The other site extreme is the area of poorly drained soils — often with rather poor aspen stands. Some of these sites can be readily planted with spruce. However, some areas are rocky or have dense vegetative cover and are costly planting chances so that it is difficult to decide what to do. We have tried different techniques but do not have ready answers. Again, some of these areas have high wildlife values.

## RESULTS OF MANAGEMENT

What are the actual results of management decisions made on the National Forests? Currently

about 25,000 acres of aspen are being given regeneration cuts annually. The area on which aspen is to be maintained is currently about 21,000 to 22,000 acres. On almost one-half of this area we are investing funds to complete the removal of residual stems. This compares with virtually no investments in aspen regeneration only 5 years ago. In the short run the proportion of treated stands will increase as we continually intensify management and work off the backlog of 3-, 4-, and 5-year-old cuts being treated. On some areas the commercial cut does a good job of regeneration and no investment in further treatment is justified. If utilization of smaller trees improves, the area that does not need treatment after the commercial cut will increase.

About 3,000 to 4,000 acres are being changed to other timber types annually. One-half of this is natural succession, primarily to hardwoods; the other half is artificial reforestation to red pine or spruce. On the other hand, harvesting in other timber types such as oak, jack pine, spruce-fir, and hardwoods is resulting in 2,000 to 3,000 acres of aspen type being created annually.

Inoperable, poorly stocked stands are also being reforested with conifers or are being treated to create new well-stocked aspen stands. We do not know the extent of natural succession of aspen to other types where there has been no treatment. Undoubtedly some of this is occurring but will only show up in our periodic timber inventories. All told we expect to see less reduction in the aspen type in the near future than has occurred in the past.

# MANAGEMENT ON STATE, COUNTY, AND PRIVATE LAND IN WISCONSIN

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**ABSTRACT.**—Aspen is managed on State and county forest land in Wisconsin under a new system. Statistical forest plans failed to meet the need. Data are now collected (23 items) from every stand. Land management printouts identify by year the individual stands that require attention for timber, wildlife, and other uses. The system provides greater personnel efficiency, stand treatment at the proper time, flexibility for changes, and coordinated input of all other disciplines. On private land, the Timber Management Guides, rotation age as determined by site index, and the owner's objectives determine aspen management.

My presentation on the management of aspen in Wisconsin will discuss a total forest management planning system rather than individual stand planning. Almost all of my allotted time will be devoted to total management planning on public land. We feel we can make our greatest contribution in the area of total management. I shall conclude with brief comments regarding the management of aspen on private land in Wisconsin.

## PUBLIC LAND MANAGEMENT

What I am about to present is a new approach to the management of any large forest holdings. It is the culmination of 18 years of work in Wisconsin by many foresters, game managers, researchers, and others. This is our first presentation on the subject. We have waited these long years until the system has become operational, field tested, and proven. It governs the management of 1.1 million acres of aspen on Department of Natural Resources and county forests in Wisconsin plus 2 million acres of other forest types.

In the 1930's, the vogue was type mapping. Since World War II, "Statistical Plans" and CFI became popular. Based upon 100 percent aerial photo interpretation, plots were allocated, data summarized, and summaries and allowable cuts were developed for each forest property.

## Need For A New Concept Recognized

By 1954, Messrs. J. A. Beale and S. W. Welsh recognized the vast shortcomings of statistical plans. They ordered further investigation into a new concept.

Field foresters in public land management were asked, "What do you want from a management plan?" Supervisors and administrators were asked the same question. Objectives were then developed.

We traveled. Other States, Federal, and industrial owners were contacted. None of the management systems viewed met the objectives we had set. Most plans were based upon forest inventory systems rather than management oriented concepts.

## Objectives of Wisconsin System

What did foresters, supervisors, and administration want? What was wrong with our statistical plans?

Field foresters wanted a plan that would answer these questions: (Does your plan?)

*Where* to harvest cut *each year*.

*Where* to make commercial intermediate cuts *by year*.

*Where* to make noncommercial cultural cuts and *when*.

*Where* are all the planting chances?

*What* stands should be considered for shearing for wildlife and *when*.

*When* markets do not absorb all the aspen, what stands are let go?

*Where* do we put public works or inmate crews when they become available?

The supervisory staff and administration wanted to know:

When research finds occur, can the plan for each forest be changed readily and rapidly?

When catastrophic losses occur, such as fire or insect mortality, can acreage control be corrected readily?

When a forester is transferred, can his replacement reach the same productive field efficiency within a few days on the job?

How many foresters are necessary on a given forest to meet the work load?

What is the necessary annual budget to do the cultural investment work?

Will a stand receive treatment at the proper time to assure maximum growth, income, and employment opportunity?

What can we expect in volume and revenue from each forest by year?

How can we manage the total forest to achieve maximum benefits to the public from timber, wildlife, and recreation?

## **New Management System Developed**

A new system was developed and implemented to answer these questions. It consists of five components:

Forest type map.

Field reconnaissance.

ADP programming.

Management printout.

Multiple-management coordination.

Let us define each component.

## **Type Mapping**

All forests are 100 percent cover type mapped and broken into compartments of approximately 700 acres each. Then individual stands in the compartment are numbered for identification purposes. We can now refer to compartment 47, stand 19 and readily identify the individual stand. Survey descriptions are too broad to use. Stands average 8 acres.

## **Field Reconnaissance**

Each stand in the forest is examined. Some 23 separate pieces of information *for management purposes* are collected for each stand including type, acres, year of origin, total height, rings in last inch, site index, basal area, volume, management objective and prescription, logging chance and operability, recreational potential, soil type, projected year of harvest, year of treatment, and remarks.

About 300 thousand pieces of detailed information on a 100 thousand acre forest are then fed into the computer.

## **ADP Programming**

Computer programs are developed to provide management data (not inventory) based upon the input of administrative decisions and latest research findings. An example will clarify.

The decisions regarding aspen were to:

Harvest at a rotation age as calculated from the site index of the stand.

Program no thinning cuts.

Program release of valuable understory.

Strive for equal age class distribution of aspen type on the forest within limits of 5 years plus or minus rotation age.

Enter a compartment twice during 15 years if necessary to prevent loss of growth or degeneration of the stand.

These are simple calculations — when done by data processing.

## **The Printout**

The printout generated shows *by year* what individual aspen stands (and other types) should be sold that year.

This is the guideline to the forester. He may vary from it. It does not usurp the forester's professional judgment when he visits the stand 5, 10, or 15 years from now. He manages the forest; we supply the guidelines.

## **Multiple Management**

Essentially only timber management has been discussed to this point. Now about the other facets of management such as game, fish, and recreation.

To assure land is managed in the public interest rather than in the interest of the discipline that administers the land, the game manager, fish manager, and other technicians plan their optimum management of the same land as if they "owned" it. Conflicts are then resolved at the lowest possible field level based upon the public need and benefit. Three examples will be helpful.

(A) A fish manager plans stream improvements on a trout stream plagued with beaver. He suggests immediate harvest of an immature aspen type that was scheduled for cutting in 1982 and a change in the management objective for the stand from natural regeneration of aspen to conversion by planting. The forestry objectives are changed to provide poor beaver habitat and more shade on the stream. The printout is altered to schedule by year a new cutting date, planting, and chemical treatment.

(B) Game management input is highly complex particularly for deer. Three separate printouts are provided the forester and game manager to assist in decision making:

1. Critical acreage determination. Wisconsin research has shown good deer habitat requires at least 25 percent aspen type within each 6,000-acre area. The printout identifies where "shortages" exist and where shearing or other treatment may be required to prevent loss of aspen to natural succession. In these areas, aspen shearing is programmed if more than 30 feet of residual basal area remain after the timber sale and if the regeneration objective is for aspen after a joint review.

2. Areas of poor site index. The poorest site index of about 15 percent of the total aspen acreage on each forest is identified. A printout schedules these stands by year for shearing or treatment on a 10-year cycle for natural food patches should the game manager so elect. Many of these stands are fully stocked but on poor sites.

3. Areas of poor operability. Aspen types of poor operability are identified on a printout for decision by the game manager as possible shearing sites.

(C) Recreation is a broad term. Esthetic management in relation to total acreage is most important.

Our public land is zoned for various uses such as established esthetic management zones. Variations in normal silvicultural cutting practices to achieve a

higher degree of acceptability are presently being developed. It will require field investigation of each stand, prescribing what will be done specifically, and recording the data for a stratified printout showing by year what is to be done and where.

It has been our experience that objectives set by one forester for esthetic management will carry on into the future and not be destroyed when he transfers only if the work is programmed and scheduled by year.

### Does the Wisconsin System Work?

Yes! The forester knows where to go to do his work. Field efficiency is improved. Stands receive treatment at the proper silvicultural time. When markets or personnel are inadequate, stands to cut and not to cut are identifiable.

With personnel transfers, a new forester can pick up the fieldwork within 2 days. When new research findings, administrative decisions, or catastrophic losses occur, all forest plans can be changed in 2 days. And, land management is maximized for wildlife, esthetics, and other products of the forest.

Does your management system provide these benefits?

### PRIVATE LAND MANAGEMENT

A staff of 57 foresters in Wisconsin assist some 8,000 private landowners annually. The equivalent of 67 million board feet was marked or designated for cutting on private land in the past year. The volume of aspen involved is unknown.

Our recommendations for aspen are based upon:

1. USDA Forest Service, *Timber Management Guide* for aspen-white birch.

2. Harvest at a rotation age according to the site index of the stand. Site index curves showing the prescribed rotation ages are used by the foresters.

3. The landowner's objectives. The pure silvicultural approach is often altered by the objectives of the landowner. Successful service foresters are masters at determining the mortgage and interest rate on the farm, the need for a new tractor, or the interest of an absentee owner in wildlife or esthetics. The needs and desires of an owner are considered in making management recommendations.

# MANAGEMENT IN ONTARIO

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**ABSTRACT.** — The management of native aspen in Ontario has progressed more slowly than that of other species. Now, however, some species which have been used traditionally by industry are slowly being supplemented, or replaced, by poplar. This increased use has emphasized the inadequacy of present inventory data for poplar species and the quality of reproduction after logging. The use of fast-growing hybrid poplars in selected areas is one of the more promising methods of meeting local shortages of native aspen.

In Ontario there is minimal management of aspen stands at the present time. This species is abundant, versatile, and productive, but in the exploitation stages of forestry pine, yellow birch, spruce, and maple have been preferred by industry. Only in recent years has aspen received any attention, and this has been sporadic, at best. An indication of increasing interest is the number of recent conferences on poplars:

1. Poplar Symposium, Harrison Hot Springs, British Columbia, 1967.
2. International Poplar Commission Meeting, Maple, Ontario, 1968.
3. Poplar Workshop, Maple, Ontario, 1970.

In government service, I have come to measure intent by expenditure. In Ontario, little has been spent to date on aspen research or management.

In the poplar working group, work has been primarily restricted to harvesting the present timber resource. For this reason, it is preferable to divide this paper into two sections:

1. Inventory and management of our present aspen resource.
2. Research developments and future management opportunities.

## INVENTORY AND MANAGEMENT OF OUR PRESENT RESOURCE

The annual allowable cut of poplar in net merchantable cubic feet in Ontario is between 400 and 500 million cubic feet. The exact figure is of academic interest only. Flowers (1970) compares three sources of data for an allowable cut, ranging from a high of 738 million cubic feet to a low of 260 million cubic feet. Ontario ranks second among the Canadian provinces, close behind Alberta, in allowable cut of poplar (fig. 1, Fitzpatrick and Stewart 1968).

Poplar represents 49 per cent of the hardwood volume and 18 per cent of the volume of all species in Ontario. The major poplar area across the north contains 78 per cent of the total poplar volume in the province with almost 50 per cent centering in the Kapuskasing-Cochrane, Thunder Bay-Sioux Lookout forest districts (fig. 2).

Perhaps more important than the actual volumes and surpluses of aspen timber is its utilization. Natural stands have been mainly harvested, not managed. The species is relatively short-lived and subject to rapid decay. In the poplar, spruce-fir types, generally only the conifer is utilized; the poplar component is not harvested. This material is inevitably wasted under present economic and ecological conditions.

Many poplar stands, originating from the large fires that occurred after the turn of the century, are now

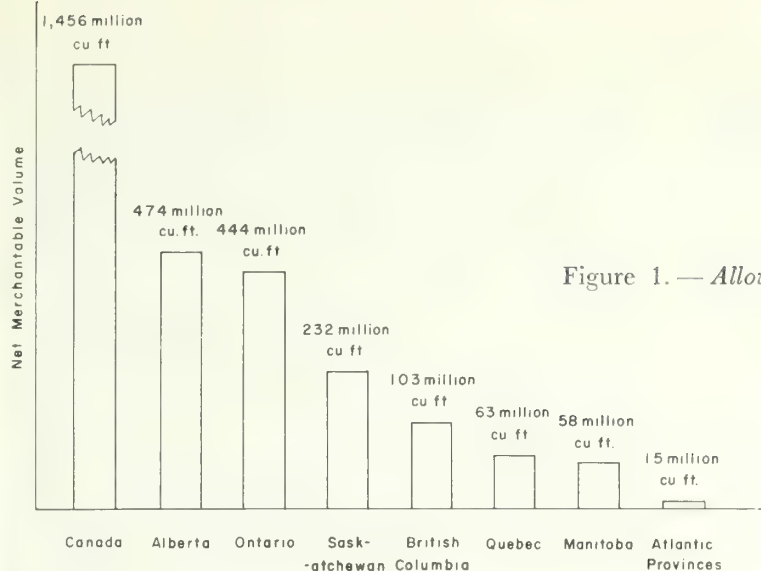


Figure 1. — Allowable annual cut of poplar. Source: Provincial Forestry Departments.

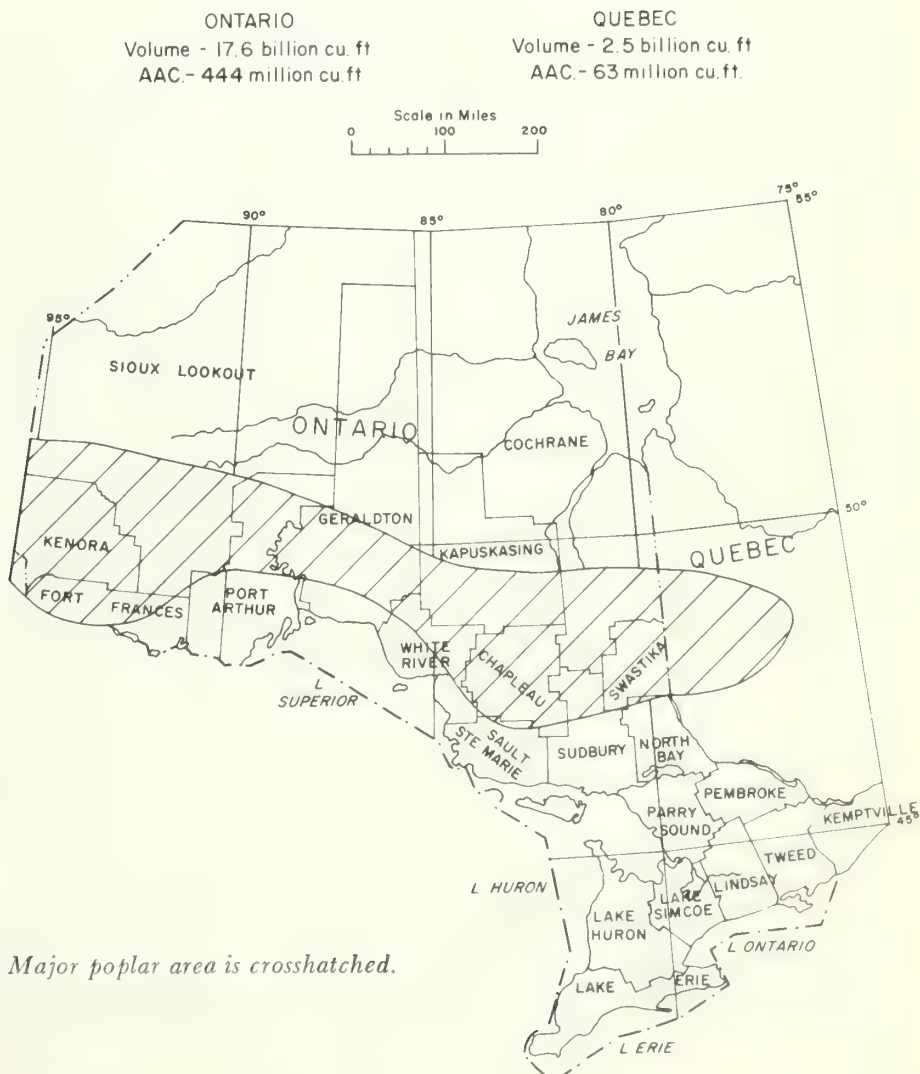


Figure 2. — Map of poplar area. Major poplar area is crosshatched.

nearing maturity. The resultant imbalance of age classes, together with the rapid decay of the species, makes projections of volume and allowable cut difficult and unreliable.

It is difficult to obtain up-to-date, accurate figures on poplar utilization for Ontario. I will use, for comparative purposes, the volume cut on Crown lands between 1956 and 1969, as reported by Flowers (1970).

The total cut of poplar is remarkably stable. This because a sharp increase in the use of poplar for new products, such as particle board and veneer, has been offset by a decrease in poplar pulpwood consumption (fig. 3). This trend has been demonstrated to be Canadian-wide by Clayton (1968).

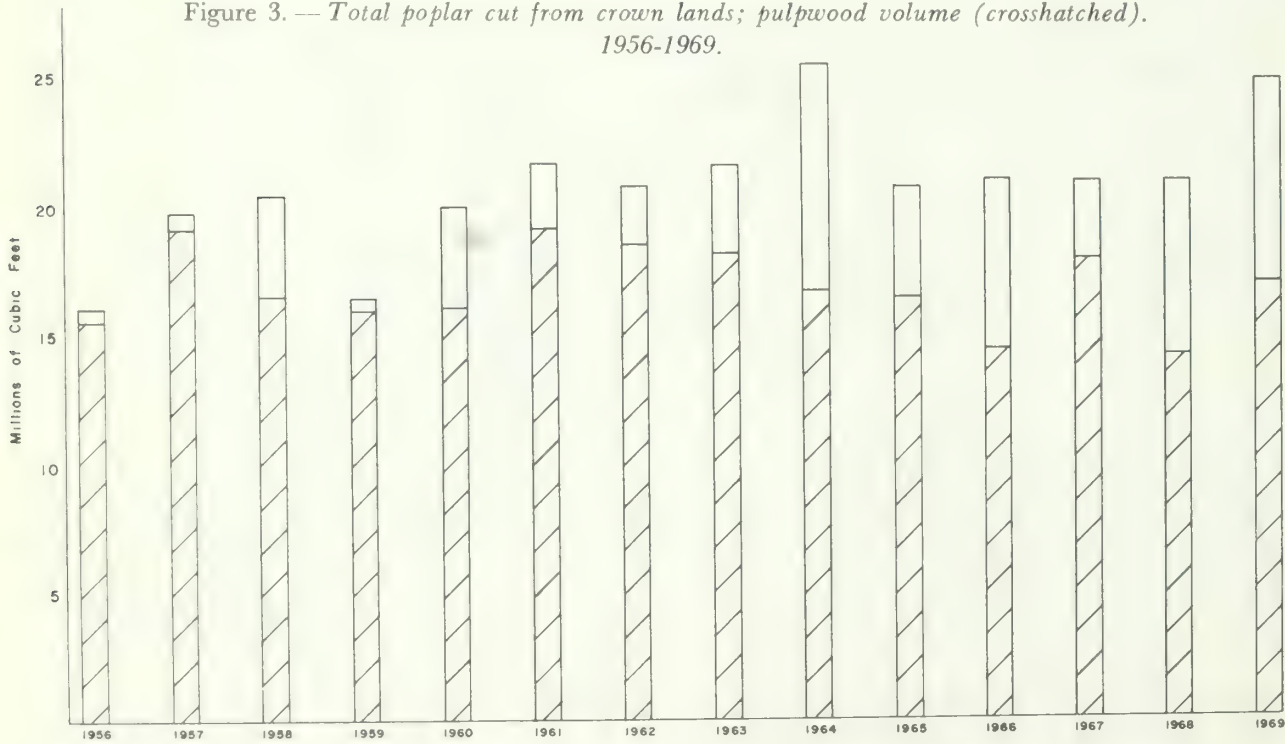
The present annual consumption of poplar in Ontario from Crown and patent land is between 35 and 40 million cubic feet. This is only 10 per cent of the annual allowable cut. When those volumes destroyed, or just not cut, from the operating areas are considered, the actual depletion figure is, in fact, much larger. Poplar is wasted in several ways: in some mixed stands, only the conifer is cut and the poplar left to deteriorate; in others, only selected quality

and sizes of poplar are cut. The latter results in top logs and the smaller and more defective trees that were part of this original merchantable volume being left in the forest. The present annual depletion in northern Ontario was estimated at 100 to 150 million cubic feet by Flowers (1970). This is 2.5 to 3 times the amount utilized by industry.

Several new plants and mills are being planned. Their requirement for poplar is not significant in relation to the volumes available. Poplar pulpwood utilization in Ontario does not show any sign of increase at the present time. However, in Ontario present conifer depletion is 670 million net merchantable cubic feet per year and is expected to reach the allowable cut of 750 million net merchantable cubic feet by 1980. Thus, future industrial expansion will mean utilization of more hardwood. This should significantly increase the demand for poplar by the year 2000.

For a species that comprises such a large percentage of the annual allowable cut in this province, poplar has received relatively little attention by research and management. This lack of interest can be attributed to poor markets, surplus allowable cut, and priorities that have directed staff and budget re-

Figure 3. — *Total poplar cut from crown lands; pulpwood volume (crosshatched). 1956-1969.*



sources toward other species. It is difficult to manage stands for which there is no market or, at best, an imperfect market.

Several investigators in Ontario and elsewhere have studied the regeneration of aspen following logging or burning. The results of these investigations to date are inconclusive, to say the least. It is generally agreed that most aspen regeneration occurs by root suckers rather than seed. Soil temperatures and light are important factors. Horton and Maini (1964) report that maximum suckering would result from clear-cutting followed by scarifying, or from a moderate intensity fire. They further report that "there is little chance of vigorous suckers becoming infected with rot from the parent stump." However, this opinion is not supported by pathological investigations of sucker-origin aspen stands.

The quality of aspen suckers resulting from a commercial logging operation leaves much to be desired. Smith (1970) reports that 100 per cent of the trees in the 15- to 20-year age class contained stain or rot. Work by Basham in 1960 gave similar results without identifying the origin, or the extent, of decay.

There is ample evidence to show that a quality problem exists in young aspen stands that originate as suckers after normal logging operations. To assist in improving regeneration quality accurate identification of sites best suited to poplar is required. A research scientist at Thunder Bay is working on this at present as part of a study on coppice regeneration of aspen. We believe that the ability to identify the site and the site requirements of the species will improve and facilitate management of both native and hybrid poplars. Investigations will continue in these areas. In addition, the hybrid poplar program carried out under the direction of Dr. Zufa, a Research Scientist, with the Department, shows considerable promise.

### RESEARCH DEVELOPMENTS AND FUTURE MANAGEMENT OPPORTUNITIES

Total timber resources in Ontario, especially poplar, exceed the present market demand. Nevertheless, there are regional deficiencies, especially in south-eastern Ontario, where large pulp mills have been operating for some time, and at other locations close

to large wood-using industries. An increasing number of wood-using industries are searching for ways to meet future raw material requirements at an acceptable cost. The use of rapidly growing species on short rotations close to the mill and grown under conditions that permit mechanized harvesting, appears to be a most promising approach to the problem.

Poplars are well suited for short rotation, high yield plantations.<sup>1</sup> They hybridize freely, and are among the fastest growing trees found in the Ontario-Lake States area. Their young growth is especially rapid. They can be propagated either by seed or vegetative reproduction, grow on a wide variety of soils and climatic conditions, and respond well to good site preparation, soil cultivation, and fertilization.

Test plantations of hybrid aspen on good poplar sites have fast growth and high yields (tables 1, 2, and 3). These plantations were established on good aspen sites prepared by ploughing. If cultivation was carried out, it was done in the year of planting. In some plantations, the young trees were repeatedly browsed.

A comparison of growth of the hybrid aspen to that of native aspen would be of great interest. Unfortunately, such a comparison cannot be made because there is no available information on the growth of native aspen in plantations. However, in order to gain some perspective, the yield of hybrid aspen was compared to the yield of native aspen, as shown in the yield tables for Ontario (Plonski 1960). These tables refer to the yield of unmanaged aspen stands and do not indicate the growth that could be obtained in managed stands. Despite these limitations, it is apparent that the yield of hybrid aspen exceeds that of native aspen on Site Class I. Average diameters at breast height (d.b.h.) in the 9- to 15-year-old plantations are similar to those attained in natural stands at 35 to 50 years of age. The average heights of trees in the 9- to 15-year-old plantations correspond to the heights of 30-year-old trees in natural stands. The mean annual increment (MAI) of the unmanaged natural stands reaches a maximum of

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<sup>1</sup> Zufa, L. *The potential of short rotation poplar plantations in Ontario. Paper presented to Int. Poplar Comm. 14th Sess., Bucharest, Romania, Sept. 27-Oct. 2, 1971 Res. Branch, Ontario Dep. Lands & For.*

Table 1. — *The yield of hybrid aspen in plantations, examples of good growth, from*

Hybrid	Location	Spacing	Age	Height	D.b.h.	Total volume	Annual increment
		Feet	Years	Feet	Inches	Cubic feet	Cubic feet
P. grandidentata x alba	Gore Bay Manitoulin Island	8	12	57	6.5	3,048	254.0
P. alba x grandidentata	Basin Depot Algonquin Park	9	15	50	8.0	2,683	178.8
P. canescens	Basin Depot Algonquin Park	9	15	53	8.1	3,488	232.5
P. canescens	Basin Depot Algonquin Park	9	15	51	7.6	3,074	205.0
P. tremuloides x tremula	Elmvale Simcoe County	10	11	54	5.9	1,422	129.2

1/ The hybrid aspens were developed and the plantations established by the Tree Breeding Unit, Research Branch, Ontario Department of Lands and Forests, under the guidance of Dr. C. Heimburger.

Table 2. — *The growth and yield of hybrid poplar in Wainfleet (Ontario) plantation at 9 years of age, 8 by 8 feet spacing; total area 1.4 acres, with 14 varieties, in 2 replications; examples of good growing varieties; figures in brackets represent selected measurement at 10 years of age, 1971*

Poplar type	D.b.h.	Height	Volume <sup>1/</sup> per acre	Mean annual increment per acre
	Inches	Feet	Cubic feet	Cubic feet
P. x euramericana cl. "I-45/51"	5.2 (5.6)	48	2,065 (2,509)	229 (251)
P. x euramericana cl. "I-65A"	5.8 (6.3)	49	2,287 (3,063)	254 (306)
P. x euramericana cl. "I-214"	4.9 (5.3)	47	1,822 (2,185)	202 (219)
P. x euramericana cl. "Regenerata"	5.2 (5.5)	39	1,700 (2,023)	189 (202)
P. alba x davidiana pop. 363	5.5 (6.0)	51	2,721 (3,262)	292 (326)

1/ Volume above 1.97 inches, based on the volume table for *P. x euramericana* cv. "Robusta" and *P. canescens*, by Sopp (1962), and calculated on the basis of the average tree of the variety times the number of trees per acre.

109 cubic feet per acre at 55 years of age, while in plantations MAI's between 103 and 326 cubic feet per acre were attained between 7 and 10 years of age (table 2).

The growth of hybrid cottonwoods in plantations in southern Ontario is shown in tables 2 and 3. The planting sites were prepared by ploughing and were cultivated in the year of planting. No other treatment

was given the plantations. The soil was heavy clay (Wainfleet) and swampy (Grand Bend). Such soils are not the best for Euramerican poplars. Both plantations were established with rooted cuttings at 8-foot spacing. At 10 years of age the trees were already overcrowded and the growth reduced because of the lack of space. Notwithstanding these negative effects, the average annual diameter growth was between 0.50 and 0.69 inches d.b.h. and the average

Table 3. — *The growth and yield of hybrid poplar in Grand Bend, Ontario, plantation at 7 years of age, 8 by 8 feet spacing; total area 1.8 acres, with 7 varieties, in 3 replications; examples of good growing varieties; figures in brackets represent selected measurements at 10 years of age, 1971*

Poplar type	D.b.h.	Height	Volume <sup>1/</sup> per acre	Mean annual increment per acre
	Inches	Feet	Cubic feet	Cubic feet
<i>P. x euramericana</i> cv. "I-214"	4.8 (5.7)	40	1,371 (2,211)	196 (221)
<i>P. x euramericana</i> cv. "Eugenii"	4.0 (5.3)	35	866 (1,796)	124 (180)
<i>P. x euramericana</i> cv. "Marilandica"	3.6 (4.8)	31	601 (1,292)	86 (129)
<i>P. canescens</i> x (alba x grandidentata) pop. 355	3.6 (4.8)		721 (1,642)	103 (164)

<sup>1/</sup> Volume above 1.97 inches based on the volume tables for *P. x euramericana* cv. "Robusta" and *P. canescens*, by Sopp (1962) and calculated on the basis of the average tree of the variety times the number of trees per acre.

annual height growth between 4.4 and 5.7 feet. At 10 years of age, the mean annual increments (MAI) of the best clones were 221 cubic feet per acre (table 3) and 306 cubic feet per acre (table 2).

In two other test plantations, established with rooted cuttings without stems on fresh sandy loams in the spring of 1969, the best Euramerican poplar clones reached an average height of 12 feet and measured 1.5 inches d.b.h. at the end of the second growing season. This growth can be considered satisfactory as it corresponds to the growth of rooted cuttings under optimal nursery conditions.

Five trees of Euramerican poplar clone I-214 were planted in a row at 20-foot spacing on a good micro site at the Maple Arboretum in the spring of 1959. At the age of 12 years, these trees measured 14.8 inches d.b.h. and 59 feet in height. The average annual growth was 1.23 inches d.b.h. and 4.9 feet in height. This diameter growth is similar to the figures published for the same clone and age on medium quality sites in Lombardy, Italy (Prevosto 1969).

These observations on the performance of Euramerican poplars in southern Ontario indicate that on good sites and under intensive management, optimal growth and high yields can be achieved. Preliminary calculations indicate an acceptable economic return

on investment over a period of two rotations. Stump-age values of \$2 to \$3.00 per cord were obtained after compounding establishment and tending costs at 4 per cent over the length of the rotation.

No valid comparison can be made between the growth of Euramerican poplars and the growth of native eastern cottonwood because of the lack of adequate information. However, the available data on the growth of eastern cottonwood indicate that selected clones of this species will perform similarly to the Euramerican poplars. According to Larsson (1970), the annual diameter growth of the best trees in a plantation of eastern cottonwood seedlings in southern Ontario, averaged 0.87 inches d.b.h. between 6 and 9 years of age.

Thus high yields can be predicted for short-rotation plantations of poplars in Ontario. The concept of poplar timber production in short rotations therefore justifies further and larger scale experimenting at least in southern Ontario. In the north, work will probably continue with native aspens at least until completely frost-hardy hybrids have been found.

Present plans are to establish annually 200 to 300 acres of plantations for timber production in the Lake Huron, Lake Simcoe, Kemptonville, and Pembroke Forest Districts (fig. 2). These plantations will consist

of hybrid aspen, Euramerican poplar, and eastern cottonwood and be designed, by spacing and type of planting stock, for pulpwood, saw log or veneer production as determined by local industrial requirements. The rotations will range from 8 to 25 years and spacing from 9 by 9 feet for pulpwood to 20 by 20 feet for veneer.

In addition, planting research will continue to select better clones and to increase the range of successful plantations. At present, we are interested in improving the performance on dryer sites and producing young wood with a greater specific gravity.

It is expected that through the careful selection of planting stock and planting areas, and the knowledge of management practices this program will make a significant contribution to poplar management in Ontario.

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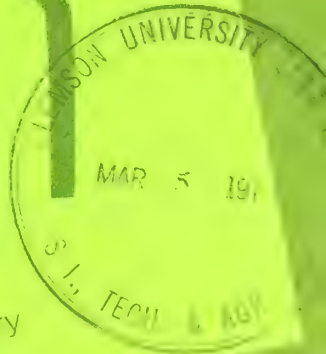
- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry\* agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
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how to use two<sup>(2)</sup>  
computational strategies  
to solve simple system  
identification  
problems



Rolfe A. Leary

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**DR. ROLFE LEARY**, Principal Mensurationist for the Station, is assigned to the Headquarters Laboratory in St. Paul, Minnesota, which is maintained by the USDA Forest Service in cooperation with the University of Minnesota.

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# How To Use Two Computational Strategies To Solve Simple System Identification Problems

Rolfe A. Leary

System identification has been defined as the process of determining a difference or differential equation such that it describes a physical process in accordance with some predetermined criterion (Sage and Melsa 1971). One should not, however, restrict it to physical processes, as many of the same principles apply to biological and social processes as well. In fact, system identification is an integral part of systems analysis, and solving the system identification problem may be viewed as one step toward the construction, testing, and analysis of mathematical characterizations of system processes. For an application of system identification concepts to the study of forest dynamics see Leary (1970).

One approach to the system identification problem (others are discussed by Sage and Melsa 1971) is to treat observations on a system as the boundary conditions governing the solution of a functional equation. Often-used functional equation types are first-order ordinary differential or difference equations. We can limit ourselves to first-order equations because any higher-order linear or nonlinear differential or difference equation may be converted to a system of simultaneous first-order equations. In most instances the only practical method of solving the resultant boundary-value problem is to use digital or hybrid (for continuous systems) computers. Generalized digital computer programs have been written to solve nonlinear multipoint boundary-value problems (Childs et al. 1969, Leary and Skog);<sup>1/</sup> however, the uninitiated are often unable to grasp the sequence of operations involved in the programs, and therefore unable to make efficient use of them. The purpose of this paper is to provide the reader with a better understanding of the methods involved so he can make better use of the available programs. We do this by presenting two step-by-step hand-computed solutions to a simplified problem using a computational strategy developed by the author and the particular solutions perturbation method (Childs et al. 1969).

We use these two methods for solving the same problem because they are implemented by available computer programs; also, we want to make it clear that one method is not necessarily better than the other but that it is the

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<sup>1/</sup> Leary, Rolfe A., and Kenneth E. Skog. A preliminary user's guide to QUASI. North Cent. For. Exp. Stn., St. Paul, Minn. 1970. (Unpublished report.)

formulation of the problem as a multipoint boundary-value problem that is important. Exactly how one solves the boundary-value problem is not crucial, because the results are identical. The problem that follows is, in fact, a simple two-point boundary-value problem. Meaningful problems will ordinarily be higher dimensional ( $>2$ ) with several boundary conditions.

## THE PROBLEM

The problem is hypothetical, chosen to minimize the hand computations. Briefly it is as follows: Assume the process of concern is thought to be governed by the set of first-order difference equations:

$$\Delta Y1/\Delta t = a_{11} Y1 + a_{12} Y2$$

$$\Delta Y2/\Delta t = a_{21} Y1 + a_{22} Y2 \quad , \text{ where}$$

$$\Delta Y1/\Delta t = (Y1(t+k) - Y1(t))/((t+k) - t),$$

$Y_i$  are system state variables, and  $a_{ij}$  are numerical constants. Assume also that  $a_{12} = .75$ ,  $a_{22} = .25$ , the initial conditions at  $t=0$  are  $Y1 = 1$ ,  $Y2 = 4$ ,  $a_{11}$  and  $a_{21}$  are unknown, and we have an observation on the system at  $t=1$ , where  $Y1 = 4.4$  and  $Y2 = 5.6$ . The question to be answered is, what values should  $a_{11}$  and  $a_{21}$  have so that  $Y1 = 4.4$  and  $Y2 = 5.6$  when  $t=1$ ?

To solve this problem we formulate it as a two-point boundary-value problem as follows:

### EQUATION 1.

$$\Delta Y1/\Delta t = Y3 Y1 + (.75) Y2$$

$$\Delta Y2/\Delta t = Y4 Y1 + (.25) Y2$$

$$\Delta Y3/\Delta t = 0$$

$$\Delta Y4/\Delta t = 0$$

with boundary conditions:

### EQUATION 2.

$$Y1(t=0) = 1, Y1(t=1) = 4.4$$

$$Y2(t=0) = 4, Y2(t=1) = 5.6 .$$

Clearly, the problem is to find initial conditions for  $Y_3$  and  $Y_4$  such that the boundary conditions are satisfied. Equation 1 with the conditions in Equation 2 is a nonlinear boundary-value problem.

## TWO STRATEGIES FOR SOLUTION

Not all nonlinear two-point or multipoint boundary-value problems are solvable. But many meaningful ones can be solved using the strategies outlined in this section. Strategy One is a variation of the method known as the method of complementary functions, and Strategy Two is the method of particular solutions (Childs et al. 1969). The essential difference between the two methods concerns the form of the linear equation for which solutions are computed. The method of complementary functions utilizes solutions of both the nonhomogeneous and homogeneous forms of the linear equation. The method of particular solutions uses solutions of the nonhomogeneous equation only. The two strategies are therefore related and have several common operations, as follows:

<u>Step</u>	<u>Operation</u>
1	Linearize the functional equations analytically.
2	Set initial conditions for solution of functional equations.
3	Solve functional equations by numerical integration or iteration.
4	Solve algebraic equations for integration constants so the boundary conditions are satisfied.
5	Form new initial conditions, $Y_{LS}(t_0)$ via superposition <sup>2/</sup> and/or check for convergence by (Strategy One) comparing $Y_{LS}^K(t_0)$ and $Y_{LS}^{K-1}(t_0)$ or (Strategy Two) checking the smallness of the integration constants.
6	If not convergent, set new initial conditions governing solution of functional equations and go to Step 3.

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<sup>2/</sup> For a discussion of superposition of homogeneous and nonhomogeneous solutions of differential equations see any basic textbook; e.g., Martin and Reissner (1961), and Bellman (1968). For difference equations consult Goldberg (1961, page 123).

## Strategy One

Strategy One is patterned after Baird (1969) and may be described by the following recurrence relations:

### EQUATION 3.

$$\Delta Y_N^K(t) = f(Y_N^K, t), \quad Y_N^K(t_0) = Y_{LS}^{K-1}(t_0)$$

### EQUATION 4.

$$\Delta Y_L^K(t) = f(Y_N^K, t) + J[Y_N^K, t](Y_L^K - Y_N^K), \quad Y_L^K(t_0) = Y_{1j}$$

where

$$\Delta Y = \Delta Y / \Delta t,$$

K is the iteration count,

N denotes the nonlinear equations,

L denotes the linear equations,

J is the Jacobian matrix at time t,

$$Y_N^0(t_0) = Y_{11},$$

$Y_{1j}$  is a constant matrix of initial conditions, the best estimates of unknown i.c., exact values of known i.c., and specified i.c. for solution of the homogeneous equations, and

$Y_{LS}(t_0)$  is the initial condition vector formed by superposition of one particular solution and one or more homogeneous solutions.

Column 1 of  $Y_{1j}$  contains the initial conditions governing the solution of the nonhomogeneous form of Equation 4.  $Y_{12}$  contains the initial conditions governing the first solution of the homogeneous form of Equation 4. Subsequent columns govern subsequent homogeneous solutions.

This strategy is different from the one usually employed in the method of complementary functions in that the initial conditions for the particular solution of Equation 4 do not change from one iteration (value of K) to the next. The primary advantage of this approach is that it minimizes relative error growth during execution of the algorithm.

The integration constants used in superposition are determined so that the boundary conditions are satisfied; i.e., by solving the system of algebraic equations:

$$y_{1c}(t_i) = y_{1p}(t_i) + c_1 y_{1h}(t_i) + c_2 y_{2h}(t_i) = BC1(t_i) \text{ and}$$

$$y_{2c}(t_i) = y_{2p}(t_i) + c_1 y_{2h}(t_i) + c_2 y_{2h}(t_i) = BC2(t_i) ,$$

where  $c$  denotes the complete solution of the linearized equation.

The operation at Step 1 for the method of complementary functions requires that we prepare the basic nonlinear system, the nonhomogeneous form of the linearized equation, and as many homogeneous forms of the linearized equations as there are unknown initial conditions. Using the notational convention  $\Delta Y1 = \Delta Y1/\Delta t$  (the first forward difference) we have:

$$\Delta Y1 = Y3 Y1 + (.75)Y2 = f_1$$

$$\Delta Y2 = Y4 Y1 + (.25)Y2 = f_2$$

$$\Delta Y3 = 0 = f_3$$

$$\Delta Y4 = 0 = f_4$$

$$\begin{aligned} \Delta Y5 &= \begin{bmatrix} Y3 Y1 + (.75)Y2 \\ Y4 Y1 + (.25)Y2 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \partial f_1 / \partial Y1 & \partial f_1 / \partial Y2 & \partial f_1 / \partial Y3 & \partial f_1 / \partial Y4 \\ \partial f_2 / \partial Y1 & \partial f_2 / \partial Y2 & \partial f_2 / \partial Y3 & \partial f_2 / \partial Y4 \\ \partial f_3 / \partial Y1 & \partial f_3 / \partial Y2 & \partial f_3 / \partial Y3 & \partial f_3 / \partial Y4 \\ \partial f_4 / \partial Y1 & \partial f_4 / \partial Y2 & \partial f_4 / \partial Y3 & \partial f_4 / \partial Y4 \end{bmatrix} \cdot \begin{bmatrix} Y5 - Y1 \\ Y6 - Y2 \\ Y7 - Y3 \\ Y8 - Y4 \end{bmatrix} \\ \Delta Y6 &= \\ \Delta Y7 &= \\ \Delta Y8 &= \end{aligned}$$

$$\begin{aligned} \Delta Y9 &= \\ \Delta Y10 &= \\ \Delta Y11 &= \\ \Delta Y12 &= \end{aligned} \begin{bmatrix} \\ \\ \frac{\partial f_i}{\partial Y_j} \quad i=j=1,2,3,4 \\ \\ \end{bmatrix} \cdot \begin{bmatrix} Y9 \\ Y10 \\ Y11 \\ Y12 \end{bmatrix}$$

$$\begin{aligned} \Delta Y13 &= \\ \Delta Y14 &= \\ \Delta Y15 &= \\ \Delta Y16 &= \end{aligned} \begin{bmatrix} \\ \\ \frac{\partial f_i}{\partial Y_j} \quad i=j=1,2,3,4 \\ \\ \end{bmatrix} \cdot \begin{bmatrix} Y13 \\ Y14 \\ Y15 \\ Y16 \end{bmatrix}$$

In the above system of 16 equations, the first four constitute the nonlinear system, the next four the nonhomogeneous form of the linearized equation, and the last eight the homogeneous form of the linearized equation. As will be clear later, the solutions of 9 to 12 and 13 to 16 above will differ because of different initial conditions. They should in fact be linearly independent to prevent ill-conditioning in the system of linear algebraic equations that is solved for the integration constants.

We are ready to begin Step 2. Let us use as initial estimates for the initial conditions on Y3 and Y4 the values 0.5 and 0.5; to ensure independence of homogeneous solutions we purposely choose Y11 = 1, Y12 = 0, and Y15 = 0, Y16 = 1. Iteration 1 follows:

Step 2: Set i.c. for functional equations

Step 3: Solve functional equations; i.e., evaluate equations 1-16 and add to i.c. to give  $Y_i(t=1)$

Y1(t=0) = 1.0	$\Delta Y1 = 3.5$	Y1(t=1) = 4.5
Y2( 0) = 4.0	$\Delta Y2 = 1.5$	Y2( 1) = 5.5
Y3( 0) = .5 estimated	$\Delta Y3 = 0$	Y3( 1) = .5
Y4( 0) = .5 estimated	$\Delta Y4 = 0$	Y4( 1) = .5
Y5( 0) = 1.0	$\Delta Y5 = 3.5$	Y5( 1) = 4.5
Y6( 0) = 4.0	$\Delta Y6 = 1.5$	Y6( 1) = 5.5
Y7( 0) = .5 estimated	$\Delta Y7 = 0$	Y7( 1) = .5
Y8( 0) = .5 estimated	$\Delta Y8 = 0$	Y8( 1) = .5
Y9( 0) = 0	$\Delta Y9 = 1.0$	Y9( 1) = 1.0
Y10( 0) = 0	$\Delta Y10 = 0$	Y10( 1) = 0
Y11( 0) = 1.0	$\Delta Y11 = 0$	Y11( 1) = 1.0
Y12( 0) = 0	$\Delta Y12 = 0$	Y12( 1) = 0
Y13( 0) = 0	$\Delta Y13 = 0$	Y13( 1) = 0
Y14( 0) = 0	$\Delta Y14 = 1.0$	Y14( 1) = 1.0
Y15( 0) = 0	$\Delta Y15 = 0$	Y15( 1) = 0
Y16( 0) = 1.0	$\Delta Y16 = 0$	Y16( 1) = 1.0

Clearly,

$$\begin{aligned}\Delta 14 &= (\partial f_2 / \partial Y_1) Y_{13} + (\partial f_2 / \partial Y_2) Y_{14} + (\partial f_2 / \partial Y_3) Y_{15} + (\partial f_2 / \partial Y_4) Y_{16} \\ &= Y_4 Y_{13} + .25 Y_{14} + 0 Y_{15} + Y_1 Y_{16} \\ &= .5(0) + .25(0) + 0(0) + 1(1) = 1\end{aligned}$$

Step 4: Solve for integration constants so boundary conditions are satisfied,

<u>Time</u>	<u>Particular</u>		<u>First homo- geneous</u>		<u>Second homo- geneous</u>		<u>Boundary conditions (observation)</u>
0	$\begin{bmatrix} \overline{Y_5} = 1 \\ \overline{Y_6} = 4 \end{bmatrix}$	$+c_1$	$\begin{bmatrix} \overline{Y_9} = 0 \\ \overline{Y_{10}} = 0 \end{bmatrix}$	$+c_2$	$\begin{bmatrix} \overline{Y_{13}} = 0 \\ \overline{Y_{14}} = 0 \end{bmatrix}$	$=$	1.0 4.0
1	$\begin{bmatrix} \overline{Y_5} = 4.5 \\ \overline{Y_6} = 5.5 \end{bmatrix}$	$+c_1$	$\begin{bmatrix} \overline{Y_9} = 1 \\ \overline{Y_{10}} = 0 \end{bmatrix}$	$+c_2$	$\begin{bmatrix} \overline{Y_{13}} = 0 \\ \overline{Y_{14}} = 1 \end{bmatrix}$	$=$	4.4 5.6

This simplifies to

$$c_1 \begin{bmatrix} 1 \\ 0 \end{bmatrix} + c_2 \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} -.1 \\ +.1 \end{bmatrix} \quad \text{or} \quad \begin{aligned} c_1 &= -.1 \\ c_2 &= +.1 \end{aligned}$$

Step 5: Form new initial conditions for the linearized equations using the superposition principle; i.e.,

$$\begin{bmatrix} \overline{Y_5(t=0)} = 1.0 \\ \overline{Y_6(t=0)} = 4.0 \\ \overline{Y_7(t=0)} = .5 \\ \overline{Y_8(t=0)} = .5 \end{bmatrix} + (c_1 = -.1) \begin{bmatrix} \overline{Y_9(t=0)} = 0 \\ \overline{Y_{10}(t=0)} = 0 \\ \overline{Y_{11}(t=0)} = 1 \\ \overline{Y_{12}(t=0)} = 0 \end{bmatrix} + (c_2 = .1) \begin{bmatrix} \overline{Y_{13}(t=0)} = 0 \\ \overline{Y_{14}(t=0)} = 0 \\ \overline{Y_{15}(t=0)} = 0 \\ \overline{Y_{16}(t=0)} = 1 \end{bmatrix} = \begin{bmatrix} 1.0 \\ 4.0 \\ .4 \\ .6 \end{bmatrix}$$

Then check for convergence by comparing initial conditions at successive iterations; i.e., compare  $Y_{LS}^K(t_0)$  and  $Y_{LS}^{K-1}(t_0)$ . When  $K=1$ , the comparison is between  $Y_{LS}^K(t_0)$  and  $Y_i$ . Thus, our comparison is:

$Y_{LS}^1(t_0)$  and  $Y_i$

1.0	1.0
4.0	4.0
.4	.5
.6	.5

Clearly, convergence has not occurred.

Step 6: According to Equation 3, the initial conditions governing the solution of the nonlinear equations at the start of iteration 2 are given by  $Y_{LS}^1(t_0)$ , the result from Step 5. Thus, in iteration 2 which follows, the initial conditions for  $Y_3$  and  $Y_4$  are 0.4 and 0.6, respectively.

Step 2: Set i.c.,  
for functional equations

Step 3: Solve functional equations, i.e.,  
evaluate equations 1-16 and add to i.c.

$Y_1(0) = 1.0$	$\Delta Y_1 = 3.4$	$Y_1(1) = 4.4$
$Y_2(0) = 4.0$	$\Delta Y_2 = 1.6$	$Y_2(1) = 5.6$
$Y_3(0) = .4$ from Iteration 1	$\Delta Y_3 = 0$	$Y_3(1) = .4$
$Y_4(0) = .6$ from Iteration 1	$\Delta Y_4 = 0$	$Y_4(1) = .6$
$Y_5(0) = 1.0$	$\Delta Y_5 = 3.5$	$Y_5(1) = 4.5$
$Y_6(0) = 4.0$	$\Delta Y_6 = 1.5$	$Y_6(1) = 5.5$
$Y_7(0) = .5$ initial estimates	$\Delta Y_7 = 0$	$Y_7(1) = .5$
$Y_8(0) = .5$ initial estimates	$\Delta Y_8 = 0$	$Y_8(1) = .5$
$Y_9(0) = 0$	$\Delta Y_9 = 1.0$	$Y_9(1) = 1.0$
$Y_{10}(0) = 0$	$\Delta Y_{10} = 0$	$Y_{10}(1) = 0$
$Y_{11}(0) = 1.0$	$\Delta Y_{11} = 0$	$Y_{11}(1) = 1.0$
$Y_{12}(0) = 0$	$\Delta Y_{12} = 0$	$Y_{12}(1) = 0$
$Y_{13}(0) = 0$	$\Delta Y_{13} = 0$	$Y_{13}(1) = 0$
$Y_{14}(0) = 0$	$\Delta Y_{14} = 1.0$	$Y_{14}(1) = 1.0$
$Y_{15}(0) = 0$	$\Delta Y_{15} = 0$	$Y_{15}(1) = 0$
$Y_{16}(0) = 1.0$	$\Delta Y_{16} = 0$	$Y_{16}(1) = 1.0$

Step 4: Solve for integration constants so boundary conditions are satisfied (from Iteration 1, Step 4, we see that conditions at  $t=0$  do not affect the solution),

<u>Time</u>	<u>Particular</u>	<u>First homo- geneous</u>	<u>Second homo- geneous</u>	<u>Boundary conditions (observation)</u>
1	$\begin{bmatrix} \overline{Y5} = 4.5 \\ \overline{Y6} = 5.5 \end{bmatrix}$	$+ c_1 \begin{bmatrix} \overline{Y9} = 1 \\ \overline{Y10} = 0 \end{bmatrix}$	$+ c_2 \begin{bmatrix} \overline{Y13} = 0 \\ \overline{Y14} = 1 \end{bmatrix}$	$= \begin{bmatrix} 4.4 \\ 5.6 \end{bmatrix}$
		$c_1 \begin{bmatrix} 1 \\ 0 \end{bmatrix}$	$+ c_2 \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} -.1 \\ +.1 \end{bmatrix}$	, thus $c_1 = -.1$ $c_2 = +.1$

Step 5: Form new initial conditions via superposition,

$\begin{bmatrix} \overline{Y5}(t=0) = 1.0 \\ \overline{Y6}(0) = 4.0 \\ \overline{Y7}(0) = .5 \\ \overline{Y8}(0) = .5 \end{bmatrix}$	$+ (c_1 = -.1)$	$\begin{bmatrix} \overline{Y9}(t=0) = 0 \\ \overline{Y10}(0) = 0 \\ \overline{Y11}(0) = 1 \\ \overline{Y12}(0) = 0 \end{bmatrix}$	$+ (c_2 = .1)$	$\begin{bmatrix} \overline{Y13}(t=0) = 0 \\ \overline{Y14}(0) = 0 \\ \overline{Y15}(0) = 0 \\ \overline{Y16}(0) = 1 \end{bmatrix}$	$= \begin{bmatrix} 1.0 \\ 4.0 \\ .4 \\ .6 \end{bmatrix}$
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and check for convergence by comparing results with those produced at Step 5 of the previous iteration; i.e., compare  $Y_{LS}^2(t_0)$  and  $Y_{LS}^1(t_0)$ . Thus:

$\begin{bmatrix} 1.0 \\ 4.0 \\ .4 \\ .6 \end{bmatrix}$	vs.	$\begin{bmatrix} 1.0 \\ 4.0 \\ .4 \\ .6 \end{bmatrix}$	, and we see that convergence has occurred.
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We may conclude, therefore, that the following equations may be used to approximate the true equations governing the observed process:

$$\frac{\Delta Y1}{\Delta t} = (.4)Y1 + (.75)Y2$$

$$\frac{\Delta Y2}{\Delta t} = (.6)Y1 + (.25)Y2$$

## Strategy Two

This computational strategy is taken from Childs et al. (1969), and may be described by the recurrence relations:

### EQUATION 5.

$$\Delta Y_N^K(t) = f(Y_N^K, t) \quad , \quad Y_N^K(t_0) = Y_{LS}^{K-1}(t_0)$$

### EQUATION 6.

$$\Delta Y_L^K(t) = f(Y_N^K, t) + J[Y_N^K, t](Y_L^K - Y_N^K), \quad Y_L^K(t_0) = Y_{ij} \quad ,$$

where all notation is identical to that in Equations 3 and 4, and where

$Y_{ij}$  is a nonconstant matrix of initial conditions, the first column of which contains the unperturbed initial conditions. Other columns contain initial conditions that have been perturbed, and

$Y_{LS}(t_0)$  is the initial condition vector formed by superimposing (in this case) two perturbed particular solutions on one unperturbed solution.

The integration constants are determined by solving the system of algebraic equations:

$$a_1 y_{1p}^1(t_i) + a_2 y_{2p}^1(t_i) + a_3 y_{3p}^1(t_i) = BC1(t_i)$$

$$a_1 y_{1p}^2(t_i) + a_2 y_{2p}^2(t_i) + a_3 y_{3p}^2(t_i) = BC2(t_i)$$

$$a_1 \quad \quad \quad + a_2 \quad \quad \quad + a_3 \quad \quad \quad = 1$$

for  $a_i, i=1,2,3$ . The third equation is a supplementary condition that the  $a_i$  must meet for this method.

The operation at Step 1 for the particular solutions perturbation method requires that we prepare the basic nonlinear system and (for this problem) three sets of the nonhomogeneous form of Equation 6. Thus we have:

$$\begin{aligned}
\Delta Y_1 &= \begin{bmatrix} Y_3 Y_1 + (.75)Y_2 \\ Y_4 Y_1 + (.25)Y_2 \\ 0 \\ 0 \end{bmatrix} &= f_1 \\
\Delta Y_2 &= &= f_2 \\
\Delta Y_3 &= &= f_3 \\
\Delta Y_4 &= &= f_4
\end{aligned}$$

$$\begin{aligned}
\Delta Y_5 &= \begin{bmatrix} Y_3 Y_1 + (.75)Y_2 \\ Y_4 Y_1 + (.25)Y_2 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \partial f_1 / \partial Y_1 & . & . & \partial f_1 / \partial Y_4 \\ \partial f_2 / \partial Y_1 & . & . & \partial f_2 / \partial Y_4 \\ \partial f_3 / \partial Y_1 & . & . & \partial f_3 / \partial Y_4 \\ \partial f_4 / \partial Y_1 & . & . & \partial f_4 / \partial Y_4 \end{bmatrix} \begin{bmatrix} Y_5 - Y_1 \\ Y_6 - Y_2 \\ Y_7 - Y_3 \\ Y_8 - Y_4 \end{bmatrix} \\
\Delta Y_6 &= & & & & \\
\Delta Y_7 &= & & & & \\
\Delta Y_8 &= & & & &
\end{aligned}$$

$$\begin{aligned}
\Delta Y_9 &= \begin{bmatrix} Y_3 Y_1 + (.75)Y_2 \\ Y_4 Y_1 + (.25)Y_2 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \frac{\partial f_i}{\partial Y_j} \quad i=j=1,2,3,4 \\ . \\ . \\ . \end{bmatrix} \begin{bmatrix} Y_9 - Y_1 \\ Y_{10} - Y_2 \\ Y_{11} - Y_3 \\ Y_{12} - Y_4 \end{bmatrix} \\
\Delta Y_{10} &= & & & & \\
\Delta Y_{11} &= & & & & \\
\Delta Y_{12} &= & & & &
\end{aligned}$$

$$\begin{aligned}
\Delta Y_{13} &= \begin{bmatrix} Y_3 Y_1 + (.75)Y_2 \\ Y_4 Y_1 + (.25)Y_2 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \frac{\partial f_i}{\partial Y_j} \quad i=j=1,2,3,4 \\ . \\ . \\ . \end{bmatrix} \begin{bmatrix} Y_{13} - Y_1 \\ Y_{14} - Y_2 \\ Y_{15} - Y_3 \\ Y_{16} - Y_4 \end{bmatrix} \\
\Delta Y_{14} &= & & & & \\
\Delta Y_{15} &= & & & & \\
\Delta Y_{16} &= & & & &
\end{aligned}$$

The first four equations above constitute the nonlinear system. Equations 5 to 8, 9 to 12, and 13 to 16 are nonhomogeneous forms of the linearized equations. The solution of these three sets may be expected to differ because of different initial conditions and should be linearly independent.

We are now ready to begin Step 2. Notice that we again estimate the unknown initial conditions on  $Y_3$  and  $Y_4$  as 0.5. Notice also that the initial conditions for  $Y_{11}$  and  $Y_{16}$  are a constant multiple (in this case 1.2) of those for  $Y_3$  and  $Y_4$ , respectively. Iteration 1 follows:

Step 2: Set i.c. for functional equations

$$Y1(t=0) = 1.0$$

$$Y2(0) = 4.0$$

$$Y3(0) = .5$$

$$Y4(0) = .5$$

$$Y5(0) = 1.0$$

$$Y6(0) = 4.0$$

$$Y7(0) = .5$$

$$Y8(0) = .5$$

$$Y9(0) = 1.0$$

$$Y10(0) = 4.0$$

$$Y11(0) = (.5)(1.2) = .6$$

$$Y12(0) = .5$$

$$Y13(0) = 1.0$$

$$Y14(0) = 4.0$$

$$Y15(0) = .5$$

$$Y16(0) = (.5)(1.2) = .6$$

Step 3: Solve functional equations; i.e., evaluate equations 1-16 and add to i.c. to give  $Yi(t=1)$

$$\Delta Y1 = 3.5$$

$$\Delta Y2 = 1.5$$

$$\Delta Y3 = 0$$

$$\Delta Y4 = 0$$

$$\Delta Y5 = 3.5$$

$$\Delta Y6 = 1.5$$

$$\Delta Y7 = 0$$

$$\Delta Y8 = 0$$

$$\Delta Y9 = 3.5 + .1 = 3.6$$

$$\Delta Y10 = 1.5 + 0 = 1.5$$

$$\Delta Y11 = 0$$

$$\Delta Y12 = 0$$

$$\Delta Y13 = 3.5 + 0 = 3.5$$

$$\Delta Y14 = 1.5 + .1 = 1.6$$

$$\Delta Y15 = 0$$

$$\Delta Y16 = 0$$

$$Y1(t=1) = 4.5$$

$$Y2(1) = 5.5$$

$$Y3(1) = .5$$

$$Y4(1) = .5$$

$$Y5(1) = 4.5$$

$$Y6(1) = 5.5$$

$$Y7(1) = .5$$

$$Y8(1) = .5$$

$$Y9(1) = 4.6$$

$$Y10(1) = 5.5$$

$$Y11(1) = .6$$

$$Y12(1) = .5$$

$$Y13(1) = 4.5$$

$$Y14(1) = 5.6$$

$$Y15(1) = .5$$

$$Y16(1) = .6$$

Step 4: Solve for integration constants so boundary conditions are satisfied.

<u>Unperturbed</u>		<u>First perturbed</u>		<u>Second perturbed</u>		<u>Boundary conditions (observation)</u>
$a_1 \begin{bmatrix} \overline{Y5 = 4.5} \\ Y6 = 5.5 \\ \underline{1.0} \end{bmatrix}$	+	$a_2 \begin{bmatrix} \overline{Y9 = 4.6} \\ Y10 = 5.5 \\ \underline{1.0} \end{bmatrix}$	+	$a_3 \begin{bmatrix} \overline{Y13 = 4.5} \\ Y14 = 5.6 \\ \underline{1.0} \end{bmatrix}$	=	$\begin{bmatrix} \overline{4.4} \\ 5.6 \\ \underline{1.0} \end{bmatrix}$

The solution is  $a_3 = 1$ ,  $a_2 = -1$ ,  $a_1 = 1$ .

Step 5: Check for convergence; i.e., are  $a_2$  and  $a_3$  very near zero?  
Because they are not we form new initial conditions via superposition; i.e.,

$$(a_1=1) \begin{bmatrix} \overline{Y5}(t=0)=1 \\ Y6(0)=4 \\ Y7(0)=.5 \\ Y8(0)=.5 \end{bmatrix} + (a_2=-1) \begin{bmatrix} \overline{Y9}(t=0)=1 \\ Y10(0)=4 \\ Y11(0)=.6 \\ Y12(0)=.5 \end{bmatrix} + (a_3=1) \begin{bmatrix} \overline{Y13}(t=0)=1 \\ Y14(0)=4 \\ Y15(0)=.5 \\ Y16(0)=.6 \end{bmatrix} = \begin{bmatrix} 1 \\ 4 \\ .4 \\ .6 \end{bmatrix}$$

and start Iteration 2.

Step 2: Set i.c.  
for functional equations

Step 3: Solve functional equations

Y1(t=0) =	1.0	$\Delta Y1 =$	3.4	Y1(t=1) =	4.4
Y2(0) =	4.0	$\Delta Y2 =$	1.6	Y2(1) =	5.6
Y3(0) =	.4	$\Delta Y3 =$	0	Y3(1) =	.4
Y4(0) =	.6	$\Delta Y4 =$	0	Y4(1) =	.6
Y5(0) =	1.0	$\Delta Y5 =$	3.4	Y5(1) =	4.4
Y6(0) =	4.0	$\Delta Y6 =$	1.6	Y6(1) =	5.6
Y7(0) =	.4	$\Delta Y7 =$	0	Y7(1) =	.4
Y8(0) =	.6	$\Delta Y8 =$	0	Y8(1) =	.6
Y9(0) =	1.0	$\Delta Y9 = 3.4 + .08 = 3.48$		Y9(1) =	4.48
Y10(0) =	4.0	$\Delta Y10 = 1.6 + 0 = 1.6$		Y10(1) =	5.6
Y11(0) = (.4)(1.2) = .48		$\Delta Y11 =$	0	Y11(1) =	.48
Y12(0) =	.6	$\Delta Y12 =$	0	Y12(1) =	.6
Y13(0) =	1.0	$\Delta Y13 = 3.4 + 0 = 3.4$		Y13(1) =	4.4
Y14(0) =	4.0	$\Delta Y14 = 1.6 + .12 = 1.72$		Y14(1) =	5.72
Y15(0) =	.4	$\Delta Y15 =$	0	Y15(1) =	.4
Y16(0) = (.6)(1.2) = .72		$\Delta Y16 =$	0	Y16(1) =	.72

Step 4: Solve for integration constants so boundary conditions are satisfied

$$a_1 \begin{bmatrix} 4.4 \\ 5.6 \\ 1.0 \end{bmatrix} + a_2 \begin{bmatrix} 4.48 \\ 5.6 \\ 1.0 \end{bmatrix} + a_3 \begin{bmatrix} 4.4 \\ 5.72 \\ 1.0 \end{bmatrix} = \begin{bmatrix} 4.4 \\ 5.6 \\ 1.0 \end{bmatrix}$$

The solution is  $a_1 = 1$ ,  $a_2 = 0$ , and  $a_3 = 0$ .

Step 5: Check for convergence. Clearly, since  $a_2 = a_3 = 0$ , convergence has occurred.

In this case also we conclude that the following equations may be used to approximate the process that was observed:

$$\Delta Y1/\Delta t = (.4) Y1 + (.75) Y2$$

$$\Delta Y2/\Delta t = (.6) Y1 + (.25) Y2 .$$

## DISCUSSION

It is clear that by following the steps outlined previously we have obtained convergence in both cases in 2 iterations. Furthermore, convergence is to the same values, as we asserted earlier. Thus both computational strategies, for which there are available digital computer programs, are suited to solve this two-point boundary-value problem.

There are at least two points that appear to warrant some discussion. First, the example selected was extremely simple and probably could be solved by other means. We would like to emphasize that the procedures used for this example apply virtually unaltered to problems that are orders of magnitude more complex; e.g., for time-dependent coefficients (nonstationary processes), "missing observation" situations, unobservable state variables, etc. For several worked examples see Leary and Skog (1972).

Second, the computational strategies employed here compare favorably with other methods of solving nonlinear boundary-value problems such as quasi-linearization, and provide an efficient method of solving a variety of meaningful problems.

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**SOME RECENT PUBLICATIONS  
OF THE  
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## ABOUT THE FOREST SERVICE . . .

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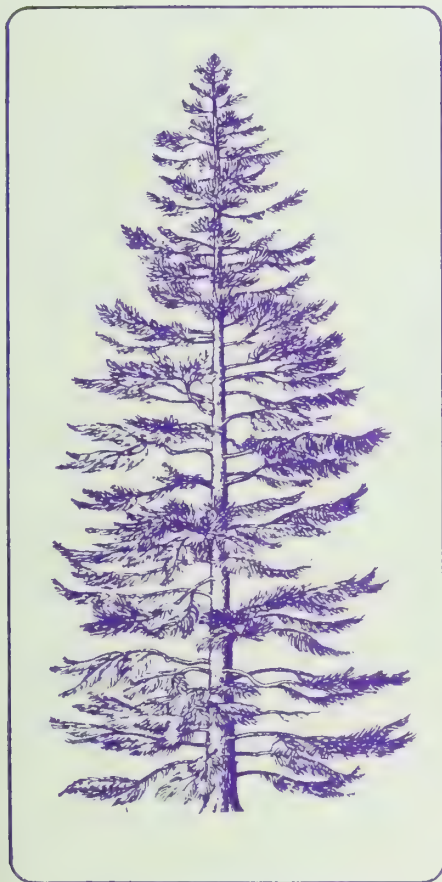
- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
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# JOINT PROCEEDINGS OF THE TENTH LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE



## and the SEVENTH CENTRAL STATES FOREST TREE IMPROVEMENT CONFERENCE, September 22-24, 1971



NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

**Mention of trade names does not constitute endorsement by the  
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**North Central Forest Experiment Station  
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St. Paul, Minnesota 55101**

(Maintained in cooperation with the University of Minnesota)

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## ACKNOWLEDGMENTS

The Tenth Lake States Forest Tree Improvement Conference and the Seventh Central States Forest Tree Improvement Conference held a joint meeting at Madison, Wisconsin, on September 22-24, 1971. The Department of Forestry, School of Natural Resources, University of Wisconsin, and the USDA Forest Service Forest Products Laboratory were the hosts.

"TREE BREEDING AND THE FUTURE FOR FIBER PRODUCTION IN THE NORTH CENTRAL STATES" was the theme of the meeting. The objective was to explore the future need and the opportunity for cooperative tree improvement efforts in the North Central States. Thanks to excellent planning, the 75 participants enjoyed a successful, rewarding meeting. The Lake States and Central States Tree Improvement Committees wish to thank the University of Wisconsin and the Forest Products Laboratory for hosting the meeting.

Since 1953 the North Central Forest Experiment Station (then Lake States Forest Experiment Station) has published the Proceedings of the Lake States Forest Tree Improvement Conference, and in 1968 the Experiment Station was partly responsible for the Proceedings of the 6th Central States Tree Improvement Conference. The Madison meeting Proceedings are published by the Experiment Station as part of the series of Proceedings. The Tree Improvement Committees wish to thank the USDA Forest Service for this valuable continued support.

### **Richard Schantz-Hansen**

*Chairman, Lake States Forest Tree Improvement  
Committee*

### **David T. Funk**

*Chairman, Central States Forest Tree Improvement  
Committee*

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# THE FUTURE OF FIBER PRODUCTION IN THE NORTH-CENTRAL STATES

W. S. Bromley, *Executive Vice President*  
*American Pulpwood Association*  
*New York City, New York*

It is an honor and a pleasure to make the initial presentation at this Tree Improvement Conference. I plan to cover the "future of fiber production in the north-central States" by confining my remarks to three major issues: (1) the potentials for expansion, (2) factors that may inhibit growth, and (3) changes in policies and procedures required.

## POTENTIALS FOR EXPANSION

Before discussing potentials for expansion, I want to be sure we have a common understanding of the main terms of my subject. For example, *fiber production* is referred to by your Executive Secretary Hans Nienstaedt from an economic and silvicultural point of view as "a crop to be harvested in a total system beginning with the harvesting of the tree *seed* and ending as a roll of paper coming off the end of the paper machine." I am sure that the combined papers of this conference may cover such a broad definition — but I will not.

In fact I want to confine the reference of "fiber" to *wood fiber production*. In doing so, I must point out that I am eliminating the possibility of a *vegetable fiber* or even a *chemical fiber* being produced before the end of this century. I mention this to assure you I am very much aware of the hazards of forecasting, and trust you will have your own reservations of long-term predictions.

I am not sure we all have the same concept of what is the North-Central Region. To pin that down, I will note that it is assumed to include the States as grouped in the Forest Resource Report 17, "Timber Trends in the United States." That grouping includes the Lake States of Michigan, Minnesota, North Dakota, South Dakota, and Wisconsin, and the Central States of Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska, and Ohio.

It is important, also, that we have a broad picture of the relative size and importance of the North-Central Region in relation to the total U.S. (including all 50 States) by noting that this region (according to "Timber Trends") has:

1. Nearly 20 percent of the total commercial forest land *area*;
2. barely 10 percent of the total *area* of *sawtimber* stands;
3. just under 10 percent of the *net volume* in growing stock trees, in terms of cubic feet;
4. about 13 percent of the total *growth* of growing stock;
5. only 8 percent of the total cut of growing stock and 10 percent of the total cut of pulpwood; and
6. more than 10 percent of the total growth of sawtimber volume but less than 7 percent of the total annual cut.

Briefly stated, the region has a minor role in the National Forest economy; it has few negative balances between growth and cut, and obviously has room for improvement and great potentials in the years ahead.

Speaking of potentials, let us now get back to the subject of potentials for expansion of fiber production in this region. Keeping in mind the relative position of the region in the national economy, I want to refer to two recent projections of national demand for forest products by two economists highly regarded in their respective fields.

The first projection (table 1) is derived from statements made by Dr. H. R. Josephson, Director of Forest Economics and Marketing Research, USDA Forest Service, in his paper at the annual meeting of Technical Association of the Pulp and Paper Industry (TAPPI) on February 24, 1971. Dr. Josephson gave statistics

Table 1. — Estimated demand for forest products in the U.S. from 1970 to 1990<sup>1</sup>  
(In million cords)

Year	Pulpwood <sup>2/</sup>	Saw logs, veneer logs, etc.	Total forest products
1970	87	100	187
1980	122	137	259
1990	167	165	332

<sup>1/</sup> From H. R. Josephson's Paper before TAPPI in New York City on Feb. 24, 1971.

<sup>2/</sup> Includes "apparent" consumption in cord equivalents of net imports of pulp, paper and paperboard products.

which indicated that "apparent" pulpwood consumption (i.e., including cord equivalents of net imports of paper, board and wood pulp) would increase from 87 million cords in 1970 to 167 million cords in 1990. The total consumption of all forest products would increase from 187 million to 332 million cords, i.e., an increase of over 70 percent in just 20 years. At this rate the total consumption of forest products would be double current rates by the year 2000.

A more conservative estimate of total demand was presented by Dr. George Cline Smith, President of Mackay-Shields Economics, Inc., at the annual meeting of National Forest Products Association (NFPA) on May 10, 1971. I have converted his estimates from cubic feet to cords by assuming 80 cubic feet to the cord; the results are shown in table 2. Dr. Smith estimates that total demand for all forest products may increase from 177 million cords in 1969 to 281 million in the year 2000. This is an increase of only 60 percent — as compared with a projected increase of 70 percent in 1990 by Josephson (or about 100 percent if projected to the year 2000). Dr. Smith's staff came up with the conclusion that the demand for sawtimber and veneer logs might increase only 10 percent annually over the next 30 years — and that most of the projected 60 percent increase by the year 2000 would be in expansion of demand for pulpwood, i.e., wood fiber.

Table 2. — Estimated demand for forest products in U.S. from 1969 to 2000<sup>1</sup>  
(In million cords)

Year	Softwoods	Hardwoods	Total forest products
1969	121	56	177
2000	183	98	281

<sup>1/</sup> From G. C. Smith's paper before NFPA in Wash., D. C. on May 10, 1971.

In light of these two competent but diverse estimates, it seems reasonable to predict that fiber production in this region should double in the next 20 to 30 years. Since consumption in this region in 1970 according to American Pulpwood Association figures (excluding Kansas, Dakota, and Nebraska) was 5,226,000 cords, we are talking in terms of 10,000,000 cords plus by the period 1990 to 2000. This seems even more reasonable when you look back 20 years and note that pulpwood consumption in this region increased just a little over 100 percent. If I had given you a prediction based on that fact alone in the first place, it would have saved us both a lot of time and words. In any case, an annual expansion of 2 to 3 percent for this region may well be the trend.

## FACTORS THAT INHIBIT GROWTH

Any estimate of the future use of commercial forest land for growing forest products, and of producing and selling such products, is fraught with more unfavorable or unknown factors than at any time in the past. I will mention only those which are most timely and significant; for example:

1. Competition for forest land is increasing. Non-timber uses and demands are increasing. Complete withdrawals from forest production are caused by parks, highways, reservoirs, and agriculture; these total as much as 10 percent of the timber cut annually for commercial use, according to Dr. Josephson.

2. The public awareness and complaints on pollution of streams, rivers, and lakes are actually closing mills, or forcing them into expensive capital investments that may make fiber production unprofitable for some mill operations.

3. Consumer programs geared to reduce or eliminate some forms of pulp and paper packaging are already getting legislative attention and support. This could seriously reduce existing production and eliminate expansion of some pulp manufacturing plants.

4. Insistence on using high or uneconomic percentages of recycled papers may seriously disrupt current and future fiber production.

5. The demand for more esthetic considerations in timber harvesting, especially in clearcutting, is causing consternation (to say the least) among practicing foresters on both public and private lands.

Surely, the above represents a serious enough list without going into the rising costs of labor, stumpage, and ad valorem taxes, or the threat of governmental interference and control of forestry practices on public and private lands, if bills such as the one proposed by Senator Metcalfe receive any favorable action by Congress. In short, even the most conservative estimates of demand may not be fulfilled unless reasonable and economic solutions are soon developed to solve these problems by our legislators.

## CHANGES REQUIRED

In spite of the threatening array of problems I have listed for your review, I am enough of an optimist to believe they will be solved to the extent that an expansion of fiber production at a 2 to 3 percent rate in this region can be expected, *providing* we take more intensive action in changing our practices and policies. When I say "our" I am referring to foresters, managers of the private and public organizations, and legislators. Some of the concerns we must include in our consideration are:

1. Our primary and immediate concern probably should be in getting more adequate information to the public and to the consumers of forest products as to what we are doing to maintain and improve our forest resources and our general environment. We must explain what may be involved in meeting the myriad of demands for improved use of water, different forms of packaging, changes in methods of harvesting forests, etc.

2. In order to meet newly established standards, our pulpmills are already embarked on massive programs to discover ways and means of using less water or of returning it in the same condition that it was prior to use.

3. Most pulp mills are using as much sawmill and other solid wood product mill residues and so-called logging wastes as is economically feasible. Studies and pilot operations on utilizing the whole tree are well underway. The recent demonstrations of the Metro Chiparvestor in this field are, I'm sure, known to you since the main plant of the manufacturer, Morbark Industries, Inc., is located in Winn, Michigan. These potentials, which can double the yield of wood harvested per cord of this region, must be explored to the fullest.

4. If there are any foresters left who feel that commercial forest land must be devoted only to the production of wood fiber or other forest products, I feel they

better seek early retirement at the first opportunity. The pressures for using commercial forest land for recreation and other nontimber growing activities require intensive application of multiple use principles.

5. Improving forestry practices and increasing production of forest products on the lands of farmers and miscellaneous private woodland owners is a major need in both this and all other forest regions of the country. This need is not likely to be met by industry, and unless it is stimulated by direct subsidies or incentive tax policies of our government, it will be a primary cause of failure in our forest policies. These ownerships (farmers and miscellaneous) comprise almost two-thirds of the commercial forest land in this region. Their improved management must be given the highest priority of attention and action.

6. Even if all the above changes were acted upon promptly and in full measure, I doubt if they would be adequate to meet the needs of our economy by the year 2000, even if we succeed in reaching zero population growth in this country by that time. Unless we have increased consideration and action on needed forest research programs, we are likely to be faced with failure in meeting our need for forest products at that time.

Our own industry sincerely believes and supports forest research. For the past 4 years, six of our own members have supported a harvesting research project that has an annual budget in excess of \$350,000. Next year the sponsorship of this program will be expanded to 12 to 15 companies. These are primarily companies with southern mill operations. I need not tell this audience that southern pulpmill operators are currently supporting some of the most intensive research in forest tree improvement, and applying the results on a region-wide basis over hundreds of thousands of acres annually. Similar efforts and programs in this region on a proportionate scale of interest and action are presently not in evidence. I am not being critical — but I do believe that all concerned with these problems in the North-Central Region should take more progressive steps to stimulate the needed research in improving the quality of seed and growing stock that will make up the future forests in this region.

I am sure the papers that follow will outline very specifically why this is needed, and how these programs would be conducted. Pay close attention and consider their recommendations with care. The future forest and the future citizens of this region will profit accordingly as you listen and act on their recommendations.

# GENETICALLY IMPROVED CONIFERS FOR THE LAKE STATES

**Jonathan W. Wright**, *Professor of Forestry*  
*Michigan State University*  
*East Lansing, Michigan*

The Lake States provenance test of jack pine was started by Paul Rudolf of the USDA Forest Service in 1951. That marked the beginning of two decades of serious tree improvement research in the region. In this paper I shall recount some of the progress that has been made. But it is also necessary to consider the extent to which genetic improvements have been put to practical use. We cannot expect continued research support without providing evidence that better trees are being planted because of our efforts.

## GREAT GAINS IN CHRISTMAS TREE SPECIES

The past two decades have seen the rise of a sizeable Christmas tree industry based upon plantation culture. Planted Scotch pine, white spruce, Douglas-fir and a few other species have all but replaced the wildlings of 20 years ago. I do not have figures for all States, but in Michigan there are about 10,000 Christmas tree growers and the annual harvest is more than 5 million trees; the good trees wholesale at prices of \$1.75 per tree and up. Tree improvement research has had a great impact on the Christmas tree industry. It is probable that between 75 and 95 percent of the nursery stock available in 1971 bears some imprint of tree breeders' activities.

Scotch pine is the most popular Christmas tree in this region. It is an extremely variable species geographically, with 4 to 1 differences in growth rate, variation from lemon-yellow to dark-green winter foliage, 2 to 1 differences in needle length, and corresponding variation in other traits. Prior to 1960, many growers planted varieties that turned yellow in the autumn; such varieties had to be sprayed with green paint at a

cost of \$0.25 per tree if they were to be sold. Also, varieties from Belgium, northern France, and the western part of West Germany were commonly planted. Those varieties have moderately acceptable color and grow so rapidly as to require that every branch be sheared every year. The introduction of dark-green, slower growing varieties from southern Europe has resulted in increased tree quality and lower production cost. The color improvement alone is worth from 0.5 to 1 million dollars per year to the growers. Also, evidence this past year indicates that southern varieties are much the most resistant to pine root-collar weevil.

White spruce is another high-volume Christmas tree. Native seed has been used most commonly. Trees grown from seed collected in eastern Ontario grow 10 to 15 percent faster, which means a reduction of 1 to 2 years in rotation length.

Douglas-fir, the high-volume Christmas tree of the Pacific Northwest, is also much in demand in the Lake States, commanding wholesale prices of \$4.75 per tree. This, like Scotch pine, is an extremely variable species geographically. Much of the stock planted prior to 1965 in Michigan was grown from seed collected in central Montana, the home of slowest growing of all races. Rotation ages of 15 to 20 years were commonly assumed to be necessary and there was little profit even at \$4.75 per tree. Now there are 10-year provenance-test data showing that Douglas-fir from Arizona-New Mexico and northern Idaho can be marketed in 5 to 8 years.

Genetics research has also resulted in improvements in four other species — balsam fir, Fraser fir, white fir and southwestern white pine. Trees of those species promise to be of premium quality and could be grown on 5- to 8-year rotations.

## REASONS FOR PROGRESS IN CHRISTMAS TREES

It so happens that most species being used as Christmas trees are extremely variable geographically. Provenance tests of a simple kind could show the presence of dramatic differences in growth rate and various other traits. It also happens that many growers in the past inadvertently chose the worst possible seed sources. Thus, it has been possible to obtain very dramatic improvements with a minimum of research effort.

Two other obvious factors should be mentioned. Christmas trees are short-rotation species amenable to quick improvement and tree breeders have paid some attention to Christmas tree problems. However, I do not think that either of these factors should be over-emphasized. The region's tree breeders have probably spent three times as much effort on timber and pulpwood problems as on Christmas tree problems.

Very important is the willingness of the Christmas tree industry to accept new developments. Christmas tree growers associations — both State and national — have annual meetings at which they solicit information on the latest developments in many areas — marketing, weed control, pest control, and new varieties. Also, these associations publish journals. All these factors have contributed to the fact that improvements have been put to practical use. The improvements have been dramatic, and Christmas tree growers have been interested in them. And, there are ways by which the information is effectively channelled to the Christmas tree growers.

Even so, success has not been automatic. It has been necessary for the researcher himself to do extension and development work. The Douglas-fir provenance test was started in 1962. A press release in 1965 elicited inquiries about recommended seed sources. No seed dealers or nurserymen handled the sources we were recommending. In 1968 we contacted foresters in Arizona and New Mexico, asking whether there was a cone crop and whether there were collectors. The replies were turned over to seed dealers. More press releases and technical articles appeared in 1970 and elicited more letters from growers and nurserymen. By that time we could recommend several seed dealers and one nurseryman as sources of Arizona-New Mexico stock. Hopefully by 1973 adequate supplies of the varieties now being recommended will be available in nurseries. Efforts such as this are necessary to make tree breeding results of practical value.

## IMPROVEMENTS IN CONIFERS FOR ORNAMENTAL PURPOSES

The ornamental use of trees is receiving increasing attention. In the southern, nonforested half of the Lake States, trees possess more economic value as parts of the environment than as producers of raw material for industry. Even in the forested parts of the region, forest policy is often dictated as much by the recreation industry as by wood-using industries, and the public may consider esthetic aspects more important than wood-producing aspects. Thus, the ornamental values of trees cannot be overlooked.

Most improvement in this area has come through the use of species from other parts of the world. Of the 10 conifers most commonly planted for ornamental purposes in the Lake States, six were introduced from Europe, western United States, and Asia. Many other species could be added to this list — Japanese larch, Serbian spruce, and metasequoia, to name three. Most of the region's tree breeders work at least a little with exotics and are acquainted with little-known species that would be useful esthetically.

With the possible exception of jack pine, all the important Christmas tree, pulpwood, and sawtimber species in the Lake States are also useful ornamentals. Virtually all the tree improvement research being conducted in this region therefore relates to ornamental use. Consider for example, the finding that one variety of white fir grows twice as fast as another. That finding is equally important no matter what the reason for planting. Or, consider an improvement in the growth rate of eastern white pine. Growth rate is important whether the white pine is planted in a park or in a forest.

Thus, research directed toward the improvement of Christmas and forest trees has developed as a byproduct a number of findings important in the use of trees for esthetic purposes. Many more such results can be expected. However, the formal tree improvement programs have had almost no impact on esthetic forestry.

Esthetic and commercial forestry are very different in spite of the fact that both may deal with the same types of problems in the same species of tree. The region's tree breeders were trained in commercial forestry and are relatively unacquainted with the problems of esthetics. This is one of the reasons why our work has had little impact on the planting of trees for ornament. We have overlooked the esthetic value of a new

variety and have not known the channels by which to communicate with landscapers.

The introduction of a new ornamental into the trade is not an easy task. Norway spruce was introduced into the United States in the 1600's but only in 1876 did it become commonly distributed in the State of Pennsylvania. Japanese larch was introduced into the United States in 1861 and has become common in New York State during the past 30 years, but is not present in Michigan outside a series of 12-year-old experimental plantations. In Michigan it has obvious merit as an ornamental (also as a timber tree), but more than 110 years might have elapsed without its being used.

I wonder whether we must wait 110 years to introduce a new hybrid pine into the towns and roadsides of southern Michigan. This is a hybrid between Austrian and Japanese red pine. It can be mass produced cheaply, may be resistant to salt spray, and grows faster than any other hard pine in the State. It should be field planted as a 2-0 seedling, and that feature is a disadvantage. Nurserymen servicing the ornamental trade are accustomed to selling larger trees at a high per-tree price. To push this hybrid, we must show nurserymen and landscapers how to make money from 2-0 trees as well as show the merits of the tree.

Any newly developed tree must be marketed through commercial nurserymen. It is they who interpret the public's needs and satisfy those needs. They are private businessmen with profits to consider. For that reason they tend to emphasize clonal lines that can be patented and thus sold exclusively by a few people. Also, they emphasize those varieties which are in demand. They reflect the needs of the suburban homeowner rather accurately, but not the needs of the highway landscaper, the inner-city dweller or the manager of a large rural park.

In recent years large chain stores have become major outlets for nursery stock. Inevitably there has been a tendency to stock only one clone or variety of a single type of tree, a variety believed to be equally successful in Maine and Oregon. This practice is a hindrance to the introduction of a new variety believed to have merit in specific situations.

Formal tree improvement programs in the region have produced many results of value to esthetic forestry, and results of a type not to be expected from amateur breeders. The channels by which those results can be put into practice have not been developed. Real efforts should be made to develop these channels.

## THE PRESENT STATUS OF IMPROVED TIMBER-TREE VARIETIES

Improvement of trees for timber production has been the major thrust of the region's tree breeders. Accomplishments, while not as spectacular as for the Christmas tree industry, have been considerable. In white spruce, increases in rate of height growth of 10 to 15 percent have been obtained by using seed collected from eastern Ontario in place of native seed. The increases would be much greater if translated into terms of volume growth. The growth differential was approximately the same whether the test was conducted in North Dakota, Wisconsin, or southern Michigan.

Norway spruce grows considerably faster than white spruce at many places in the southern and central parts of the Lake States. Also, it grows well in Michigan's Upper Peninsula and some other northern areas. On many sites, spruce rotations could be reduced 25 to 50 percent if this species were substituted for white spruce. Norway spruce is subject to attack by white-pine weevil and suffers from old age when it reaches a diameter of 18 inches. Even with those difficulties, Norway spruce grows straight and fast and to greater size than do our native species.

Eastern white pine from the southern Appalachians planted 12 years ago in southern Michigan is now 25 feet tall, surpassing native trees by 10 to 15 percent. Eastern white pine trees from southern Ontario are nearly as tall as those from Tennessee, although not as large in diameter. In tests conducted in Michigan's Upper Peninsula, white pines grown from seed collected in the Lower Peninsula grew 8 percent taller than Upper Peninsula trees. In experiments conducted in northern Wisconsin and northern Minnesota, trees from central Wisconsin grew most rapidly.

It is apparent that no one race of eastern white pine is best for all portions of the Lake States. But it is also apparent that there is a better type of white pine for almost every acre in the region. Increases of 10, 20 or even 30 percent in rate of volume growth can be expected by a judicious choice of seed sources adapted to particular sites.

Comparable gains have not been obtained in jack pine, where the fastest growing trees are from central Wisconsin and central Michigan. Jack pine growers in those areas should use local seed. There is evidence that moving central Wisconsin-central Michigan seed

northward into northern Wisconsin and parts of northern Michigan (but not into northern Minnesota) can result in a 5 to 10 percent gain in growth rate without encountering winter damage.

Plus-tree selection followed by grafting is the tree breeding method most commonly used in northern Europe and southeastern United States. Its possible usefulness in the Lake States has been tested by means of progeny tests. These are now well underway in five coniferous and one hardwood species. Except in white spruce, the results are negative — plus trees as selected in the fields have not produced superior offspring.

However, another breeding method known as family selection has been tried with some success. The goal of this method, as of plus-tree selection, is to make use of the genetic variability believed to be present in any natural forest for the production of a new variety superior to the wildlings now on the land. A red pine progeny test-seed orchard developed along these lines indicates a 2 to 3 percent gain in rate of height growth, with limited quantities of seed to be available in 1975. Although nursery measurements of a similar jack pine project indicated gains, measurements made 4 years after field planting leave the issue in doubt.

It is still too early to talk of the amount of improvement in tamarack, northern white-cedar, and balsam fir. There are sizable projects underway with these species but the experiments are young yet.

Japanese larch, unlike its relative the tamarack, is a moist upland species. It is a remarkably fast-growing species. Trees planted 12 years ago in northern Minnesota, northern Michigan, southern Michigan, and Nebraska are 1½ to 2 times as tall as neighboring pines and spruces planted at the same time. This rapid growth has made it an important timber species in New York and northern Europe.

Most of these improvements are not being put to practical use, partly due to a lack of a sustained drive on the part of researchers. The results have been publicized more in scientific journals than in newspaper releases and popularized articles that would be read by tree planters. Also, a certain amount of developmental work is necessary before some of the results can be put into practice. In this regard, I think we could borrow from the experience of the user-oriented North Carolina State-Industry program, where use of research data has received as high a priority as the scientific aspects.

Both researchers and tree planters have been loath to accept the results from 10- to 15-year-old experiments as final. We have tended to be overcautious. Undoubtedly some new varieties that show great promise at age 10 will not look so good at age 50. But this will not happen to all new varieties. In deciding to plant something that has been only partially tested, we run a certain risk. But in deciding not to plant anything new, we face the certainty of not improving our forests in the next half century.

The breeding and introduction of a new crop plant variety are only partly under the control of a plant breeder. He makes the original selections, crosses them, develops the new variety, and tests it in experimental plantings. Then he releases it to the public for commercial use, and that is when the real testing starts. Many such new varieties fall by the wayside over the years but a few succeed and raise the general level of agricultural productivity. I think we should follow this agricultural practice and make sure that our new tree varieties receive extensive testing under actual field conditions.

One way to accomplish this with minimum risk is to plant each new variety in gradually increasing amounts in small plantations or even in mixed plantations. One scheme suggested for eastern white pine in southern Michigan is to raise 100,000 Tennessee white pines, give them to nurseries, and ask the nurseries to provide each white pine buyer with 25 percent Tennessee stock and 75 percent Michigan stock. A one-row to three-row mixture would permit testing of the Tennessee trees on a broad scale with little risk.

There has been an unfortunate tendency to consider genetic tree improvement as an alternative to silvicultural management. Instead, we should consider genetic improvement and silvicultural management as complementary procedures. The new varieties will give the greatest amount of improvement if planted on good sites, given good weed control, and given proper management.

## IMPROVED TIMBER VARIETIES OF THE YEAR 2,000

I have dwelled on the problem of putting research results to use because we will not have continued support for tree breeding research unless there is evidence that the results have been useful. Also, the tree planting public must become accustomed to the use of new varieties.

The past 30 years saw a tremendous amount of forest planting in the Lake States. Most of the public lands badly in need of cover are now forested. These plantations are providing a source of raw material for industry. Public response to this policy of maximum wood production from every acre has been varied and as of 1971 the wisdom of continued large-scale planting is being questioned from many sides. The wisdom of planting only for timber production is also being questioned. Thus there is no clear mandate for a tree breeder to concentrate on a single species such as white spruce or red pine that would be excellent for industrial use. Nor is there a clear mandate to concentrate on volume production or any other single trait such as wood quality. The needs both as to species and uses will continue to be varied, so I see a continuation of the present practice of working on a wide variety of species and problems.

Nevertheless, increases in growth rate will continue to loom large. Growth rate is an easy thing to measure, progress in increasing growth rate has been shown, and the demonstration of rapid growth is an easy way to obtain research support. As an example of the possibilities, I will cite red pine. The Michigan red pine progeny test-seed orchard program was started in 1961 and by 1975 should yield improved seed. There is promise of a 2 to 3 percent gain in rate of height growth. Plans are already made to start a second-generation progeny test-seed orchard program in 1975. This will use control-pollinated seed and should produce about twice as much gain as the first generation. If the heritability estimates are correct, we may obtain a total gain of 10 to 15 percent in rate of height growth by the third generation, about the year 2005.

Similar projects are planned or underway for other important species — white spruce, white pine, jack pine, and Scotch pine. Such projects are relatively inexpensive, requiring strong effort at intervals of 10 to 15 years and little effort between times. Present data indicate that the gains would not be changed very much by intensifying the effort and concentrating on a single species.

Increased disease resistance is needed in several species. Preliminary results are promising but indicate that we may have to wait some time for truly adequate varieties. I will cite an example from Scotch pine. The Belgian variety is the fastest growing and among the most susceptible to the European pine sawfly and the pine root-collar weevil. The Ural Mountain variety is resistant to the sawfly but not to the root-collar weevil and grows 25 percent slower than the Belgian variety. The Yugoslavian variety is resistant to the root-collar weevil but not to the sawfly and grows 15 percent slower than Belgian trees. It seems likely that we can obtain a good timber variety combining rapid growth, sawfly resistance, and resistance to the root-collar weevil by crossing the three varieties and selecting among the offspring for about five generations.

White-pine weevil is another important insect. Preliminary results from two different types of experiments indicate that there is little hope of obtaining a resistant variety by selection and crossing of eastern white pines in less than 20 or 30 generations. But, western white pine carries a satisfactory amount of resistance and can be crossed easily with eastern white pine. A three- or four-generation hybridization project could give us a resistant variety well adapted to the Lake States.

To tackle the production of these two resistant varieties of trees would be a new undertaking in tree breeding. It would require the preparation of 50-year work plans calling for a series of crosses to be made and test plantations to be established at intervals of 10 to 15 years, faith that the end products would justify the effort, and a single-minded concentration on getting the work done.

Becoming sidetracked is one of the greatest dangers in a long-term project such as I've outlined for Scotch pine and white pine. The approach is old-fashioned, similar to that followed by crop plant breeders for the last 50 years. There are possibilities of shortcuts — of finding a method of rooting unlimited numbers of cuttings of one good early-generation hybrid, of finding the internal cause of resistance, or of hastening flowering so that generation length can be reduced to 50 years.

# GENETIC IMPROVEMENT OF HARDWOOD FIBER PRODUCTION IN THE NORTH-CENTRAL REGION: POTENTIALS AND BREEDING ALTERNATIVES

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In the Lake States, aspens are now growing towards senility faster than they are being harvested (Groff 1966). In the Central States, wood processing residues have recently supplied about one-half of the area's hardwood fiber requirement (Blyth 1970), thus allowing hardwood growing stock to continue its recuperation. In fact, the national hardwood fiber supply situation is improving (Hair and Spada 1970). However, a growth deficit is expected by the year 2000, given current management levels and "expected" demands. Josephson (1971) foresees about another decade of adequate fiber supply. Moreover, some of our economists tell us poor biologists that we've got to produce more and more fiber on less and less land. Somewhere between the unharvested senility of aspen and an unrealistic commitment to unrelenting growth, we must settle on a varied, productive forest to supply a stable, fiber-using industry.

Einspahr and Benson (1970) see three aspects to this forest: (1) certain lands for recreation and amenity with timber as a byproduct, (2) some areas for conventional timber management, and (3) good sites near mills for intensive short-rotation fiber production. Genetic improvement of fiber production has a role in all three of these settings. Despite the obvious intellectual and short-range economic attractions of research on intensive hardwood fiber production systems, geneticists, physiologists, and silviculturists must address themselves to the problems of all three levels of practice. Genetic improvement of hardwood fiber production must be considered within the framework of forest management's several regional goals, not as an isolated objective.

We can assume from previous analysis by Dawson and Pitcher (1970) that genetic improvement of hardwood fiber species in the North Central Region is a high priority research and development goal. They conclude that effort should be concentrated on aspen and cottonwood for which there are respectively about 8 and 4 million acres of highly productive sites in the region. Most of my discussion will thus center on probable first generation genetic gains in these species, especially aspen, which have not been subjects of recent review. However, data will also be noted for other northern species such as birch, maple, and oak, for which highly justifiable breeding programs are aimed mainly at improvement of lumber and veneer material; improvement of these species' growth capacity can ultimately add to our fiber supply. Finally, I will briefly review recent data for some southern hardwoods, because they suggest first generation gains that may be expected in north-central species. We will consider growth, wood properties, and pest resistance.

## COTTONWOOD

Cottonwood breeding programs are aimed mostly at providing genetically improved material for intensive cultural systems. While these systems may produce lumber and veneer as well as pulpwood, they do so in fairly short rotations (20 to 30 years on excellent sites), at least in the lower Mississippi Valley. Conventional forestry techniques are presently used in pulpwood rotations, but cottonwood may be suitable for "silage" systems. Breeding programs should therefore produce material for both conventional intensive forest management and new methods of fiber production.

Mohn will discuss cottonwood breeding methods in a later paper at this meeting, and Schreiner (1971) has outlined a detailed cottonwood breeding system. My remarks will deal only with expected gains. Most of the data are for populations in the South and are not patently applicable to North-Central Region populations, but they represent a fair estimate of what may be expected farther north.

First, racial variation may be the source of considerable gain in the North-Central Region. Mohn and Pauley (1969) noted that while much material from 32° to 38° latitude was winter killed at a 44° planting site, surviving low-latitude plants exhibited much better second-year growth than local stock (6.0 feet vs. 4.4 feet). Further screening of 32° to 38° sources at higher latitudes should provide some valuable breeding populations for northern areas. A large provenance test now under way in Illinois may produce some of this material.

Most of the southern breeding effort has been concentrated at the USDA Forest Service's Southern Hardwoods Laboratory. The early work of Wilcox and Farmer (for review see Farmer and Mohn 1970) consisted mostly of field selection of good phenotypes followed by short-term (1 to 2 years) screening tests of clones and open-pollinated families grown under intensive culture. Genetic gains computed from test data were expressed as percentages of control populations, the means of which were equal to or slightly above a natural population. Expected genetic gains in height and diameter from selecting the top 10 percent of clonal populations were around 5 to 10 percent. Because of correlation between height and diameter, expected volume gains were 10 to 20 percent. Gains for specific gravity were estimated at 7 percent and for fiber length about 4 to 5 percent. Other characteristics related to growth, such as phenology and *Melampsora* rust resistance, were found to be more highly heritable in these and other (Jokela 1966) tests. Mohn and Randall (1972) have reexamined one of the Wilcox and Farmer (1967) tests at 6 years, and report slightly higher heritabilities than noted for first- and second-year growth, thus suggesting that early gain estimates for growth were probably conservative.

Forty clonal selections made from these screening studies were planted along with a control population of 40 clones in a larger test, and some 4- and 5-year growth data have been published by Mohn and Randall (1969), Randall and Mohn (1969), and Mohn *et al.* (1970). At 4 years, mean volume per tree for the 40

selections was 27 percent greater than for controls, indicating that preliminary selection in screening tests was effective. After the fifth growing season, when a second thinning (to 109 trees per acre) was made, 14 clones were selected from the study for further testing and pilot-scale commercial use. On a good cottonwood site, the mean volume of these 14 clones was 6.5 cubic feet per tree, compared with 3.7 cubic feet per tree for the control population. Three of the clones had mean volumes in excess of 100 percent over controls. The gain represented by these selected clones is realized gain on the test site, not predicted response computed from genetic parameters. Intensive clonal screening and testing should soon result in a number of clones with this sort of growth capability, because the initial breeding population represents only a minute portion of available material.

Exactly how much gain in growth was made in each of the various stages of selection noted above is difficult to determine from available data. Analysis by Mohn and Randall (1969) indicated some gain was made in field selection of phenotypically superior parent trees and at the other stages thereafter. In a 2-year, open-pollinated progeny evaluation using the same selected parents and a 52-family control population, Farmer (1970) observed identical means for juvenile growth of controls and selected families, and concluded that field selection had been ineffective. In this latter test, predicted response (genetic gain) to combined selection of the top 5 percent of the test population was 7 percent for height, 16 percent for diameter, 10 percent for specific gravity, and 5 percent for fiber length.

The Texas Forest Service breeding program includes clonal tests of local selection and material from throughout the eastern U.S. To date, local clones have proven superior in eastern Texas, and after preliminary testing, nine were recently compared with nursery-run material in a 4-year-old irrigated test.<sup>1</sup> The best clone, with an average tree volume of 4.0 cubic feet, is producing nearly twice the volume of controls and 45 percent more dry weight. Cottonwood twig borer (*Gypsonoma haimbachiana* Kearf.) damage, which is serious in Texas tests, has not varied appreciably among rapid growing local clones, but was found to be low in a hybrid poplar clone (Woessner and Payne 1971).

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<sup>1</sup> Woessner, R. A. Growth, volume, and dry weight differences among 4-year-old *Populus* clones grown under irrigation. Pap. presented at First North Amer. For. Biol. Workshop. 1970.

It thus appears that early estimates of genetic gain in southern cottonwood populations may be conservative and actual juvenile volume gains of up to 100 percent may be realized in first generation selection if enough clones are screened. Numerous tests and pilot plantings are now in progress throughout the Mississippi Valley, and the resulting data should shortly give a reliable estimate of realized gains on a per-acre as well as a per-tree basis. Data from these tests should substantially augment our scanty information on wood properties and pest resistance. Concurrent studies of growth relationships (Larson and Gordon 1969) may provide keys to effective screening for superiority in fiber production.

## ASPENS

Genetic information on the aspens can be applied effectively at all three levels of silviculture noted above. The considerable amenity value of an aspen clone is not reduced if it is uncommonly healthy and rapid growing. A recreationally oriented silviculture aimed at a continuous supply of esthetically pleasing aspen will certainly produce fiber. The deer-aspen system of producing game and fiber pioneered by Westell (Graham *et al.* 1963) presents good opportunities for using genetically superior clones. Aspen's clonal habit and regeneration by root suckering enhance the potential long-range benefits of using genetically superior clones on lands managed with traditional techniques. Einspahr and Benson (1968) have already cited the important benefits of short-rotation aspen silviculture.

Early studies of phenotypic variation in growth and wood properties of Wisconsin quaking aspen were reported by Buijtenen *et al.* (1959), who took advantage of aspen's natural clonal habit to obtain rough estimates of broad-sense heritability. Expected gains from selecting the best 5 percent of the population were: height, 10 percent; diameter, 6 percent; specific gravity, 2 percent; and fiber length, 4 percent. Barnes (1969) used the same procedure to estimate broad-sense heritability for height and diameter of *P. tremuloides* and *P. grandidentata* in Michigan. His estimate for trembling aspen diameter was similar to that of Buijtenen *et al.* (1959), but his heritability for height was lower. Heritabilities for height and diameter ( $h^2 = 0.34$ ) of *P. grandidentata* were higher than for trembling aspen. All of these estimates of heritability and gain are probably biased upward, since in studies of unreplicated clones, environment and genetic effects are confounded.

Broad variation in growth of naturally occurring clones of both aspens has also been reported by Einspahr

and Benson (1967), Koenig (1960), and Romeril (1961). Einspahr and Benson used growth data for trembling aspen in Wisconsin to establish base lines for judging potential field selections. In Koenig's study of bigtooth aspen in Michigan, 28 clones were selected for their phenotypic superiority in growth, and were paired with randomly selected adjacent clones. Selected clones had trees that averaged 12 percent taller, were 19 percent greater in diameter, and contained 53 percent more volume than random clones. Six selected clones on the best site sampled had 166 percent more volume than random clones. Romeril extended this sort of selection study to a wider area in Michigan and designated 16 phenotypically superior clones that contained trees 15 percent greater in diameter, 13 percent taller, and with 51 percent more volume. Zahner and Crawford (1965) have shown the importance of considering clonal variation in aspen site evaluation; their data on phenotypic differences are in agreement with those above. Because of aspen's natural replication, these variation data are more meaningful in terms of potential gain than similar phenotypic variation information for other species. They suggest good progress may be had through clonal selection and testing.

Variation in aspen wood properties has been most recently reviewed by Kennedy (1968) and Pronin and Lassen (1970). It is sufficient to note here that most phenotypic variation studies suggest that prospects for improving fiber properties and specific gravity through breeding are good, but specific estimates of genetic gain from clonal selection are lacking except for those of Buijtenen *et al.* (1959).

While the insects and diseases of aspen are well known (Graham *et al.* 1963), and there is some information on variation and inheritance of pest resistance (Schreiner 1963), data that might be used to estimate gains are rare. A study by Copany (1969) of clonal variation in susceptibility of trembling aspen to *Hypoxylon pruinae* (Klotsche) Cke. represents the kind of work that will be prerequisite to breeding efforts. This pathogen causes an estimated annual loss of 1 to 2 percent of standing volume (Anderson 1964). Copany surveyed 88 clones on five sites in Michigan, and reported that on a poor site infection ranged from 10 to 83 percent. Study conditions suggested that much of this interclonal variation has a genetic basis. Preliminary observations by Einspahr<sup>2</sup> indicate that hybrids

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<sup>2</sup> Personal communication with D. W. Einspahr, Institute of Paper Chemistry, Appleton, Wisconsin.

involving *P. alba*, *P. canescens*, and *P. grandidentata* parentage may be more resistant to *Hypoxylon* than quaking aspen.

The discovery of triploid quaking aspen clones in Michigan and Wisconsin (Buijtenen *et al.* 1957, 1958) led to interest in their fiber-producing merits relative to diploids. Comparison with adjacent diploid trees indicated that triploids were significantly faster growing in one area but not in another. Wood properties were studied in one area; triploids had significantly longer fibers, but there was no difference in specific gravity. A study of phenotypic variation among 20 trees from four triploid clones suggested that differences in growth and wood properties were under moderate to strong genetic control (Einspahr *et al.* 1963). Subsequently, a formal 10-year comparison of two triploid clones with two diploid full-sib families (Benson and Einspahr 1967, Einspahr *et al.* 1968) revealed no significant triploid superiority in growth, form, and specific gravity; triploid fibers were no longer than diploid. In another test, the mean 5-year growth of three triploid clones was about 20 percent greater than that of nine diploid, full-sib families (Einspahr and Benson 1964); the report did not include a statistical comparison, however.

Aspen hybrids of *P. tremuloides* x *P. tremula* have been tested in Europe for several decades and are believed to be distinctly superior to the local *P. tremula*. Larsen (1970) has reviewed the numerous reports of this work; my comments will cover American tests. Ten-year results from the New England screening tests of Pauley *et al.* (1963) indicated that crosses involving Massachusetts *P. tremuloides* females and *P. tremula* males from mid-latitudes of Europe or from Italy performed best, with height growth of 2 to 3 feet per year.

Hybrids of German *P. tremula* and Massachusetts *P. tremuloides* have been compared with local *P. tremuloides* stock in an unreplicated Wisconsin test (Church 1963). At 12 years, the hybrids averaged 24 feet in height and local stock 21 feet. In a 5-year replicated test, Benson and Einspahr (1967) noted that two families of triploid hybrids (*P. tremula* x *P. tremuloides*) grew 3 and 4 feet per year while two local diploid families grew 2.5 and 3 feet. Specific gravity of the triploid families was about 0.4, compared to 0.36 and 0.38 for the diploid. Other reports (Barnes 1961, Pauley 1956) note existence of natural hybrids and suggest their breeding possibilities. In short, hybrids have been successfully grown in the North-Central Region, but large-scale screening and testing will be required before estimates of gain can be made. Some of this work is in

progress at the Institute of Paper Chemistry (Einspahr and Benson 1964).

While no replicated progeny tests in aspen have been reported, Einspahr *et al.* (1967) studied variation in growth and wood properties among 25 full-sib families planted in single blocks on a uniform site. Narrow-sense heritability estimates, based on progeny-parent regression information, indicated moderate possibilities for genetic improvement of growth and moderate to good genetic control over fiber length and specific gravity. Einspahr (1968) has brought together the limited published heritability data, then assumed parent trees were to be two standard deviations better than the population mean, and predicted average genetic gain that might be obtained from full-sib families of these parents. Some of these estimates are presented below:

Improvement characteristics	Estimated means*	Average expected genetic gain (Percent)	Absolute gain
Height growth, ft./yr.	3.00	10	0.300
Diameter growth, in./yr.	.25	11	.030
Volume growth, cu. ft./A./yr.	100.00	20	20.000
Specific gravity, g./cc.	.38	4	.015
Fiber length, mm. (age 10)	.80	6	.050

Systems for genetically improving aspen fiber production could take several forms. Selection of a breeding system and investment level should be hinged on a formal analysis of the relationship between improved material and management, as proposed by Namkoong *et al.* (1971). Perhaps the simplest procedure might consist of roguing existing stands in appropriate situations, a silvicultural measure recommended by Graham *et al.* (1963). Recent information on the nature and development of natural clones (Barnes 1966, DeByle 1964, Garrett and Zahner 1964, Tew *et al.* 1969) suggest techniques for such roguing. Rogued clones might

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\* Estimated means for 8- to 10-year-old diploid quaking aspen plantations growing at a moderate rate of growth.

be replaced with genetically improved material, or existing phenotypically good clones might be expanded. The results would be a genetically variable and superior stand obtained without the high cost of complete conversion.

I see no major barriers to development to commercial vegetative propagation procedures based on known techniques (Farmer 1963, Benson and Schwalbach 1970); thus selection and testing of naturally occurring clones appear feasible. Because of natural replication, field selection in aspen is probably more effective than in other hardwood species. A clonal selection program might gradually evolve into one aimed at development and commercial use of parents with high specific combining ability. Schreiner (1971) has outlined such a breeding system for cottonwood; it is equally applicable to aspen. Given any of several possible systems, however, it will be important that (1) some large, well-designed tests be established to give badly needed genetic information, (2) field selection be extensive enough to obtain a genetically diverse breeding population, and (3) control populations used in breeding tests be large enough to truly represent natural population means.

## OTHER HARDWOODS

Northern breeding programs in birch, oak, and maple, and southern efforts in sweetgum, sycamore, and yellow-poplar have been under way for several years. The impact of these programs on fiber production in the North-Central Region will be variable and will depend on the manner in which improved stock is used. Analyses of the relationships between tree improvement research and action programs and establishment and management plans are particularly important for the fine hardwoods with their relatively long rotation. Improved stock of some sawtimber and veneer species may not be planted at traditional spacings in single species plantations. Rather, this material may be "inserted" in regenerating natural stands at crop-tree densities (i.e., 50 to 100 stems per acre), and cultural methods during establishment may center on these individual trees rather than on the whole stand. Recreational and esthetic benefits may be major management goals in these forests. In such a system, improved growth potential would not be reflected in pulpwood production for at least one rotation. On the other hand, breeding in species such as sycamore and sweetgum is aimed at intensive plantation culture of pulpwood and sawtimber, and genetic gains can be immediately realized.

Information on yellow birch, northern red oak, sugar maple, and white ash is available from provenance tests. In a 3-year-old rangewide birch test in Wisconsin (Clausen and Garrett 1969), there is wide, but apparently random, variation in growth. Seedlings from the best source were twice as tall as those from the poorest one and 32 percent taller than the local Wisconsin stock. First-year heights of northern red oak from southern sources (e.g., Tennessee, southern Indiana, Arkansas) grown in northern Ohio were 30 to 100 percent greater than those of oak from more northern sources (Kriebel 1965). Family (open-pollinated) differences were also prominent, and Kriebel concluded that selection of individual seed parents will be important in improving growth rate. Fourteen-year data from the sugar maple study (Kriebel and Gabriel 1969) also indicated that, in northern Ohio, trees from the central portion of the distribution of the species complex grew better than trees from other sources. Low juvenile 11-year correlations in other tests suggested, however, that early selection for growth is not practical, though juvenile narrow-sense heritability was moderate ( $h^2 = 0.28, 0.30$ ). While no major breeding programs in ash are now in progress, results of Wright's (1962) early provenance tests indicate the existence of southern ecotypes that may outgrow local stock in some portions of the North-Central Region. In brief, information to date suggests that some major improvements in northern hardwood growth may ultimately be based on provenance test results confirming non-optimality of local races (Namkoong 1969).

Sycamore (*Platanus occidentalis* L.) has received most attention in the South as a candidate for "silage" culture (Herrick and Brown 1967). Webb (1970) has analyzed 2- and 3-year data from an evaluation of 64 randomly selected open-pollinated families growing on a good site at 4- by 4-foot spacing. Genetic gain in height from combined selection of the best 5 percent of the population was estimated to be 6 percent. Heritability estimates for third-year growth parameters in this test, which have not been published, suggest that gain will be considerably more than 6 percent.<sup>3</sup>

A number of well-designed and potentially valuable sweetgum progeny tests have been established, and some reliable estimates of gain in juvenile growth will soon be available. The only heritability estimates published to date are those of Wilcox (1970), based on a population of 40 open-pollinated families from southern

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<sup>3</sup> Personal communication with C. D. Webb, U.S. Plywood-Champion, Inc., Athens, Ga.

Mississippi. Narrow-sense heritability was 0.25 for 3-year height on a site in central Mississippi, and 0.40 for height on a Gulf Coast site. While Wilcox did not publish data essential to estimating genetic gains, means and family ranges suggest that at least 10 percent genetic gain in growth could be obtained with a selection intensity of 5 or 10 percent. A larger (81 open-pollinated families) test of material from throughout the lower Mississippi Valley is planted on two contrasting sites in central Mississippi, and Schmitt and Webb (1970) have briefly noted some 6-year results. These data indicate the possibility of major gains in growth through a combination of source and family selection in the test plantation. The data so far do not make an encouraging case for mass selection in the field.

Yellow-poplar which should provide some fiber in the southern portion of the North-Central Region, has been subjected to some provenance testing with varied results (for review see Wilcox and Taft 1970), and it is as yet uncertain what sort of gain may be expected from source selection. At least one open-pollinated progeny test has, to date, produced no evidence of significant familial variation.<sup>4</sup> At present it is apparent that early estimates of gain must await full-sib tests now in progress.

One further comment on breeding in this group of species is appropriate. As Schmitt and Webb (1970) have noted, early data from a number of tests suggest that mass selection in natural stands of most hardwoods will probably not lead to good first generation gains in juvenile growth potential. They recommend that "more effort be devoted to establishing sizable breeding populations rather than refining phenotypic selection in wild populations." I believe this recommendation is particularly pertinent to rapid progress in genetic improvement of fiber production.

## CONCLUSIONS

Review of existing published data on variation and inheritance of growth and wood properties in hardwoods suggests that at least 10 to 20 percent improvement in fiber production can be realized in first generation selection. Prospects of indirect improvement through pest-resistance breeding appears good, though based on little data. Because aspens are the predominant pulping species in the North-Central Region, and because they

possess silvical characteristics that are assets to breeding, a major investment in their genetic improvement would be profitable in the long run. Realization of possible genetic gains in aspens and other species will depend on early implementation of judiciously selected applied breeding programs and on increasing improvement-oriented regeneration investments. To ensure wise investment in research and development, early analytical attention must be given to the relationship between improvement programs and the establishment and management of genetically superior stock.

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# THE FUTURE SUPPLY OF CONIFEROUS TIMBER FOR LAKE STATES INDUSTRY

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I feel a bit like the onion in the petunia patch today. Here I am, a professional timber beast, trying to tell a bunch of geneticists how to run their genes. However, I do believe that the practical success of the forest geneticists' work is dependent not just on their abilities, but also partly on someone else's knowledge of the real need for tree improvement. So, we will try to pass on to you people some of the understanding that we butchers have for wood markets and availability, both today and to some degree in the near future. Particularly, we will concentrate on the coniferous species.

In the Lake States, we have a total volume of coniferous timber of about 10 billion cubic feet. This figure does not include the timber standing on public lands dedicated to other uses than forest management, but it does include the trees on a lot of forest area that is not available to the timber user. The amount of wood available to the wood-using industries is closer to 8 billion cubic feet than the 10 billion.

At the present time, the actual annual harvest of Lake States conifers for all wood purposes is in the neighborhood of 140 million cubic feet. About half of this wood is cut in Minnesota, the other half in Michigan and Wisconsin.

Of this 140 million cubic feet of coniferous wood that is harvested each year in the Lake States, the paper industry is by far the principal user. About 85 percent of all of this wood is used in the pulp mills. Because of this single overwhelming use, and because I happen to have a better understanding of pulpwood than I do of other kinds of raw wood, from now on my talk will be primarily relevant to the pulp mills.

Let's go back again to the 140 million cubic foot harvest of coniferous wood. Except for jack pine, Lake States conifers are being harvested very conservatively.

The total cut of all species amounts to only 60 percent of the estimated desirable cut. Only two species were higher than this 60 percent figure — jack pine, which is being harvested at an annual rate of 120 percent of the desirable cut, and spruce, which is being cut at a 70 percent rate. The species that has the greatest amount of surplus volume is balsam fir, of which only one-third of the desirable cut is being used (fig. 1).

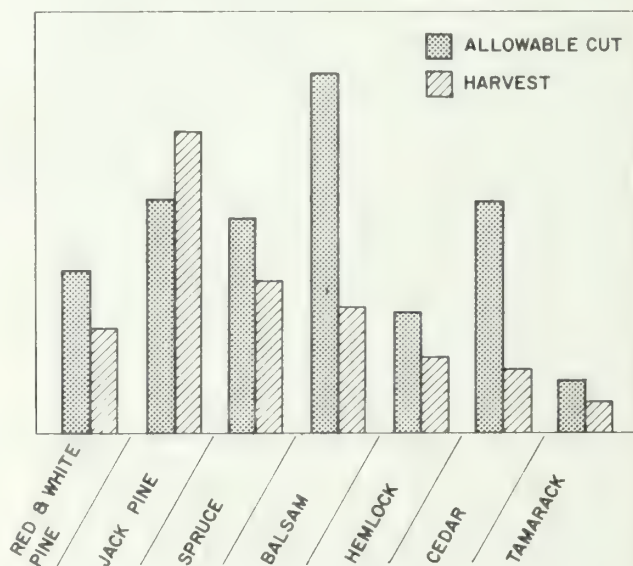


Figure 1. — Allowable cut and harvest in the Lake States.

The use of softwoods in the Lake States has been relatively stable during the past 15 years — varying between 1.6 and 1.8 million cords (fig. 2). However, the use trends of individual coniferous species show a considerably different pattern. For instance, in 1956 spruce was the king species; then over the last 12 years its use has been cut in half. Balsam, also, has been on the skids. But pine use has been climbing steadily, and

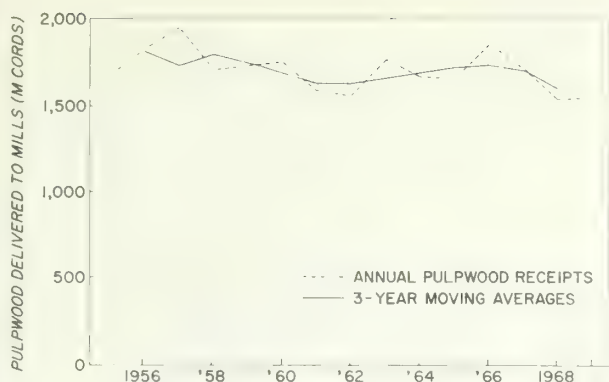


Figure 2. — Trend in use of long-fiber wood in Lake States pulp mills.

chips (mostly pine sawmill waste) have more than doubled in the last 5 years. Hemlock and tamarack use has been quite stable, but they are minor items in the total wood procurement picture (fig. 3).

If my estimates of desirable cut are reliable, and I don't guarantee them, we have at the present time a good surplus of coniferous timber in the Lake States. If there were no restrictions on quality and species, the Lake States softwood-using industries could increase their production by about 80 percent and still be within the bounds of the desirable cut. But these restrictions do exist because of technological, economic, and geographic problems. So, our current situation here is not quite as cozy as the numbers indicate.

The pine pulpwood situation in Wisconsin is a good example of the geographical disproportion between the sites of the paper mills and the location of timber. Wisconsin pine forests are providing the Wisconsin kraft mills with only 35 percent of the pulpwood of these species. This amount of wood is at the limit of the combined desirable cut for all of the Wisconsin pines. Wisconsin mills receive about 15 percent of their pine pulpwood from Upper Michigan, where current harvest of jack pine exceeds desirable cut; and 10 percent from Minnesota, which has some surplus pine. The three Lake States provide 60 percent of Wisconsin's pine needs. The other 40 percent comes from the western States — from the Black Hills and as far away as Idaho. About two-thirds of this western wood is waste material from sawmills — material that was formerly burned (fig. 4).

Now, if this was all that needs to be said about softwood availability in the Lake States, I could go back to my office, sit down in a comfortable chair, and re-

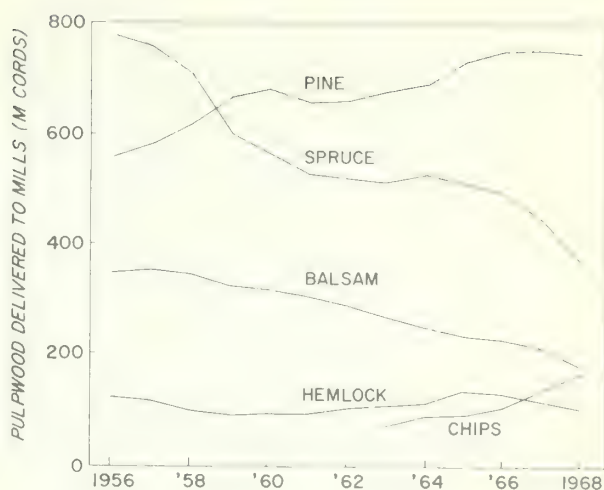


Figure 3. — Components of long-fiber pulpwood delivered to Lake States pulp mills.

mind myself occasionally that the only problems I would have in wood procurement were weather and car shortages; and you geneticists could head for your laboratories and perform all sorts of interesting experiments with no thoughts at all about applying your knowledge to something practical.

But it ain't like that, fellows. For instance, the pine-using mills in the Lake States are dependent upon the western forests and sawmills for 250,000 cords of wood annually. Right now, we are anticipating an increase in western freight rates; an increase that could be so great that it would knock the props out from under these chips as a useful and desirable source of wood. Or worse yet, there is a possible regulation on clear-cutting on the eastern slopes of the Rockies. This could put many western sawmills out of business, and there go our chips again. I am not kidding you about these catastrophes — they are both serious and possible. What do we have to replace our western wood? Principally the surplus balsam and cedar in the Lake States, and these are two species that provide very poor pulp yields.

We have mentioned that there is now a surplus of softwood in the Lake States. But this is not going to be a perpetual premium to the local wood-using industries. There are in sight some factors that will cause changes in the need for coniferous wood and the availability of it.

Let's look at some of these factors that will affect the need for wood. First, the pollution regulations will

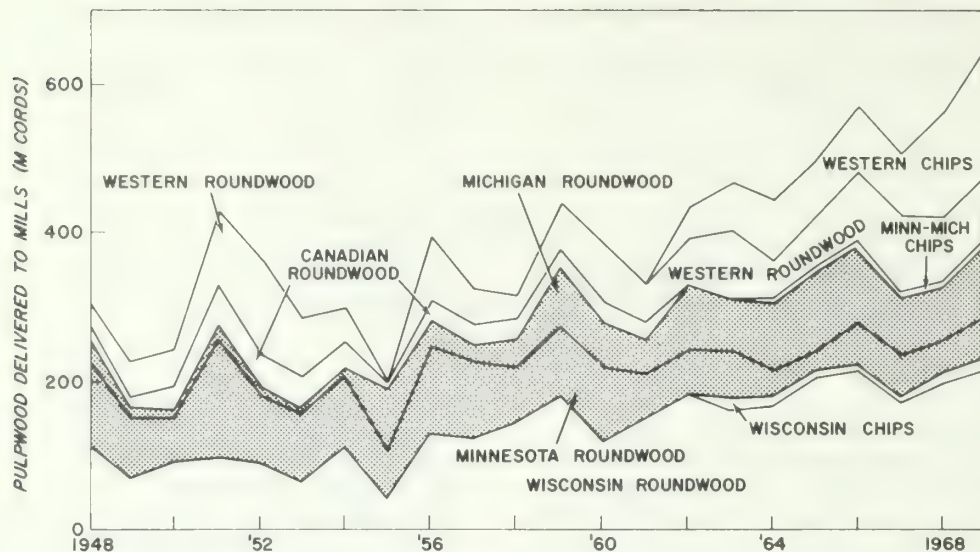


Figure 4. — Sources of pine for Wisconsin pulp mills.

very likely put out of business some of the Lake States pulpmills. We are talking here about some of the old sulfite mills that are principally softwood users. If this does happen, we can expect that most of this abandoned wood will be absorbed by the expansion of other mills.

And then we have the prediction that there will be substantial increases in the national need for the products of the wood-using industries. Certainly, the wood reservoir of the Lake States is not being overlooked — it will provide its share of both softwood and hardwood timber.

These estimates of major increase in wood use appeared to be quite grim when they were first presented. But they appear grimmer when we look at current changes in forest land use; and grimmest when we consider some of the proposals being offered by the environmentalists.

I have seen no figures on the amount of forest land that has been recently withdrawn from timber harvesting in the Lake States but it certainly is a sizable area, and it will become larger. There have been many changes in ownership of private forest lands and much of this will not be available for timber production. Recreation developments by public agencies are being expanded on Federal, State, and county lands that have formerly been considered to be timberlands. The establishment of the Voyageur National Park will swallow a large area of well-managed, private coniferous forest.

The Apostle Islands development is on the edge of one of the large jack pine areas in Wisconsin and the park could put some of this timber in jeopardy. Probably the worst afflictions we have are the newborn environmentalists, ecologists, and preservationists who are proposing the arresting of clearcutting and, indeed, the outlawing of all logging on public lands. Something like this gets serious when presumably perceptive federal lawmakers propose legislation along these lines.

All of these forces are going to cause the timber people a lot of trouble, although the worst of them are not likely to happen to the degree that the proponents are asking.

Now, what can we do about this besides standing here wringing our hands? The first act, of course, is to get involved in the politics of these movements. But there are a lot of other things, too. New technology in the mills is necessary. The paper industry already has increased the reuse of rejected or used fiber and waste materials. Synthetic fibers are being tested. Sawmill and veneer mill equipment is being improved. Better wood handling and processing in the yard and mill is necessary. In a pulpmill that uses 300,000 cords of wood, a 3½ percent loss in the wood system causes the use of 10,500 more cords of wood than is necessary.

What can the foresters do? Better forest management, by all means, and better coordination between management and the research people. When I compare the

correlation of management and research in the Lake States with that in the South and parts of the West, I am amazed at how backward we are. And, of course, we need a better forest management program for small ownerships — a program sponsored by the Forest Service, the States, and industry.

The forest engineers have the task of developing ways of getting better utilization of the wood in the forest. Morbark's Metro-system is a start at this. The bark-chip separation research is another step.

Now, you geneticists sit here sort of quietlike. But don't kid yourselves — we have a job for you, too. You are the people who we expect will provide us with trees that have excellent fiber, very high yield, faster growth, insect and disease resistance, and response to fertilization and irrigation.

I am serious. This is the 10th annual meeting of the Lake States Forest Tree Improvement Committee and I know that the organization has existed about 10 years longer than this period. To my knowledge, we still do not have a superior coniferous tree that will

grow faster than the plain, ordinary, everyday red pine on the proper site. The fault is not really yours; there has so far been little interest in using your skills. Nor is it completely the fault of the forest managers; they have never seriously approached you mainly because no one really had anticipated the situation that lies before us.

I have presented to you my ideas of the problems that the wood-using industries, and our total society, are facing in the availability of coniferous wood. Frankly, I do not feel that we are capable of telling you tree improvers what help you can give us or how you should do it. We do not have the background that you have developed. But I do believe that you can be a real help to us if we can work together. I am not asking for your help in just the development of strains of trees that furnish high yield plantations, but also in other facets of forest management on the millions of acres of Lake States forest land that are not adaptable to the agricultural type of forestry.

If we need a slogan for this job, let's put it this way: You furnish the protoplasm; we furnish the dirt.

# WHAT DOES INDUSTRY NEED THAT TREE IMPROVEMENT CAN PROVIDE? SHORT-FIBERED SPECIES

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*Tomahawk, Wisconsin*

(Unfortunately, Dr. Valley was unable to submit a manuscript of his presentation at the meeting. The following short summary was prepared by Dr. D. T. Lester and approved by Dr. Valley.)

Dr. Valley emphasized the importance of cost control in industrial forestry. He pointed out the necessity of a systems approach to cost reduction. The Morbark Metro Harvesting System was discussed as an example of technological innovation, with implications covering several facets of the paper production process.

Other contemporary concepts of wood processing, including the long-wood system and the silage system, were mentioned. The trend toward utilization of smaller

trees and shorter rotations was mentioned. Bark removal was noted as a problem in newer harvest approaches and the possible application of genetics to facilitate bark removal was suggested.

Dr. Valley illustrated the decreasing development time between invention and commercial utilization of technological improvements. The holopulping process in which milder digestion increases recovery of usable carbohydrates was presented as an example of modern technological innovation.

# TREE BREEDING AS A FOREST MANAGEMENT SUPPLEMENT — ECONOMICAL, SOCIOLOGICAL, AND ECOLOGICAL CONSIDERATIONS

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*Champion Woodlands Division*  
*U.S. Plywood-Champion Papers, Inc.*  
*Decatur, Alabama*

To set the stage for my remarks, I would like to tell a story I recently heard. The top management of a large corporation has just ordered installed two IBM machines in the accounting department. Two middle-aged men — the office manager and his assistant — received the news with some misgivings. They felt that things were progressing well in their office; the accounting was being done adequately at an acceptable cost by a room full of attractive secretaries. As these men viewed the attractive labor force, the manager was overheard to remark to his assistant, "Do we really want to replace all this with a computer?"

There are several aspects of this story that might apply to the many forest industries and foresters: (1) change comes more frequently from top management and usually for economic reasons — less often for sociological or ecological reasons; (2) lower echelon personnel are often reluctant to change because things are satisfactory as they are; and (3) many of us are locked into a stereotyped notion of what an office should be like — or of what a tree, a board, or fiber should be.

It should be no surprise to most of you here when I say that the forest industries have always been interested in tree improvement — in reverse order to what most geneticists consider as tree improvement!

In 1605, Captain John Weymouth of the British Royal Navy nosed his ship into one of the harbors of what is now the coast of Maine. His men cut samples of northern white pine timber, which he took back to England. Captain Weymouth's efforts to inform his countrymen about the quality of the timber in North America were highly successful — especially with the

Royal Navy. Suitable trees in the New England forests were marked with the king's broad arrow and thus reserved for the exclusive use of the Royal Navy (Simmons 1949). Thus began industry's interest in the superior tree!

The search for and the use of the superior tree by industry throughout our history, for legitimate and commendable reasons, also led to the reduction of a desirable genetic base from which to perpetuate our future timber supplies and continues today in many areas. The term for this rather distasteful timber harvesting technique is "high-grading."

Like the office manager and his assistant, forest industries and foresters have responded to and accepted change only when they have found it economically necessary. Large-scale planting was not undertaken until the lack of wood resources became a very real possibility. Innovation in logging techniques came on the scene only when the economics of wood production dictated a change, or because the lack of labor made it physically impossible to harvest a sufficient quantity of wood. The same might be said of tree improvement; acceptance by industry and foresters resulted when it became economically attractive or necessary, or because a potential shortage of raw material required a new approach to plantation management. Dr. Ernst Schreiner advocated and promoted tree improvement and breeding in the New England area 30 to 40 years ago. But industry's tremendous capacity for innovation in utilization standards that would make the plentiful lower grades of fiber more acceptable made tree improvement unattractive then. Apparently, the same situation holds true today. Dr. Schreiner

wrote me “. . . the growth potential of the present forest is sufficient to supply the needs of the north-eastern industries without the need of silvicultural management; taxes are so low that there is no need or incentive to invest in silvicultural or tree improvement practices that could increase the per-acre production of fiber and timber.”

Dr. Robert McElwee of the Virginia Polytechnic Institute, Blacksburg, Virginia, recently wrote me concerning his efforts to set up a cooperative tree improvement program in Maine. “Primarily for the north-east, and I suspect also the Central States, the main hindrance to any meaningful tree improvement is economics. By this, I do not mean that growth rates are so slow that tree improvement is not justified, but rather that land-holding patterns are such that despite sizeable outputs in terms of paper and other products, increased production is not needed and cannot be justified where other production costs also increase. For example, Maine produces sizeable quantities of paper annually as well as many other forest products. Ninety percent of the timberlands in Maine are in eight owner-ships, the largest being 2¼ million acres owned by one company. It is easy to see that with minimal growth rates of ¼ to ½ cords per acre annually, and many sites far exceed this, cut is under growth. Currently in Maine, cut is 60% of growth with natural regeneration and 70 - 90 year rotations. Similar cut-drain ratios are found in other New England states and to me there is no way to justify additional expenditures for any silvicultural practices, including tree improvement.” Does this cut-drain ratio apply to the North-Central Region?

The rather substantial strides in cottonwood culture in the Mississippi Delta came about as a necessity to generate local fiber and eliminate excessive transportation costs. Fortunately, tree breeders and tree improvement specialists had many of the necessary answers to start an operational tree improvement program.

The Texas, Florida, and N.C. State University programs were established in the 1950's at the specific request of industries who came to the universities and asked them to undertake a cooperative effort. To quote Dr. Zobel, Director of N.C. State University Cooperatives, “The Cooperative Tree Improvement Program was initiated in 1956 at the School of Forest Resources at N.C. State University at the request of 11 pulp and paper industries. There are now 22 members. Though the cooperative was initially an industry program, the

state forestry organizations of North and South Carolina and Virginia requested to join and were admitted.”<sup>1</sup> The story on southern hardwoods is similar —

“During the past decade, two factors have largely been responsible for intensified interest in southern hardwoods. First, the quality of hardwoods have been depleted to the point that the demand can no longer be met; and secondly, advance technology within the pulp and paper industry has made hardwood pulp a necessity instead of a liability for the manufacture of specialized products. As a result, the hardwood cooperative was formed in 1963 with 10 charter members... . The present membership is 17 industry cooperators and one state forestry organization. Perhaps the greatest impetus to the success of the Tree Improvement Programs has come from the members of the cooperative themselves. Dozens of special studies have been initiated dealing with all facets of tree improvement... . These made possible research results and information useful in forest management and mill operations that could not have been otherwise available. The activities of the program can be broadly described as follows:

(1) Applied tree improvement involving seed production, seed orchard establishment, and genetic improvement of trees used in regeneration.

(2) Research on wood qualities, wood variation, and inheritance.

(3) Training of graduate students, accompanied by research activities of a very diverse nature, from theoretical quantitative genetics to seed orchard management.

(4) Basic research on inheritance, quantitative genetics, population genetics, speciation, wood properties, and others. (*Note the priority.*)

“The tree improvement program is a mixture of applied and basic research. Impressive results have been obtained in a short period of time because the program has a central theme: IMPROVE PINE BY WHATEVER METHOD POSSIBLE.

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<sup>1</sup> *Tree Improvement Short Course, North Carolina State Univ. at Raleigh, Jan. 1971.*

"The objectives of the hardwood research program differ markedly from those for which the tree improvement cooperative was formed. The reason for this divergence is that hardwoods had been ignored over the past half century while basic information on regeneration, management, yields, and inheritance patterns were being obtained for the southern pines. Consequently, it becomes necessary to derive basic information before any program dealing with hardwood tree improvement can be launched. The basic philosophy of the hardwood research group, however, is to discourage deep involvement in hardwood tree improvement until basic information is obtained."<sup>1</sup> McElwee emphasized this last point with reference to New England —

"The second deterrent (is), despite all the ballyhoo to the contrary, (that) very little meaningful research is available as background with regard to species, site quality, soils data, and other types of information necessary before tree improvement can be meaningfully implemented."

Dr. Ray Goddard of the Florida Tree Improvement Cooperative says: "In my opinion, tree improvement is attractive to industry only when they are involved in large scale artificial regeneration. A few companies will support basic research on a limited scale but widespread acceptance comes when they can see rather direct application to their own needs. In any region with little or no intensive management, or where primary dependence is on natural regeneration, there is little incentive for support of tree improvement." The N.C. State Cooperatives discourage participation unless landownership totals a minimum of 200,000 acres.

So, as in the case of the IBM machines and the secretaries, economies must be apparent and the physical base must be sufficient (but not too large) to justify a change — in this case, tree improvement.

To paraphrase Gertrude Stein: a tree is a tree is a tree. And like the office manager, foresters are reluctant to change because things are progressing as they are. Many of us are content to produce the same old tree in the same old way; we are locked into a stereotyped notion of what a tree is and how we should plant, grow, and harvest it. If we get fiber, fine; if we happen to reap a little grade so much the better. Philip Larson, Chief Research Plant Physiologist, Rhineland, Wisconsin, puts it very nicely (Larson 1972):

"Unfortunately, our forestry traditions regarding the growing, harvesting, and utilizing of trees have not left us in such a favorable position to cash in on the green revolution sweeping agriculture. We are still pretty much dependent upon the tree nature gave us. Even today, our concept of an ideal tree is essentially an imitation of the ideal tree growing in a natural forest. Because of past tradition of timber abundance, we haven't felt the need to really put our imaginations to work to seriously consider how we might alter or restructure a tree to produce more wood."

I have been, and am, an advocate of agri-forestry — the use of agricultural land for the production of fiber and quality along with food crops, if necessary (White 1971). The economical, sociological, or ecological considerations have not made this practical yet, but these pressures may require such intensive use of land in the future. It seems to me that the sooner we embark on an agricultural type of forestry program, the better acceptance we may have by the environmentalists. We may be permitted to utilize our professional knowledge to provide them with the things they will not do without. I see no reason why foresters should not consider growing wood on agricultural ground; the farmer, the horticulturist, and the orchardists do not rely on wildland to produce consumer needs — nor does society expect them to! So all we need now is for Phil and I to get together — he with his nontraditional concept of tree growth, and my heretical suggestion of the use of agricultural land — and we could make a significant contribution to future wood requirements.

Using these concepts, I can visualize tremendous increases in wood productivity, a considerable reduction in land base with consequent savings in taxes, transportation, personnel, and harvesting costs. What might the economies be if, instead of our traditional dependence upon whatever wood fiber is available, a mill could count on fewer species, genetically tailored for the product, and intensively planted, cultured, and harvested? How much does it really cost industry to harvest, transport, and utilize the myriad of species from far-flung, unmanageable holdings? Agri-forestry would permit the ultimate in the utilization of personnel and resources — possibly to the point where fiber could be planted, grown, and harvested on a 24-hour-a-day basis, utilizing all the benefits of fertilization, irrigation, and genetically improved stock. The forest fiber land base could be greatly reduced and yet produce a greater volume of wood. Surplus lands could be devoted to other uses, and we would perhaps be able to

relieve social and ecological pressures while making economic gains. Tree improvement in the South was conservatively estimated to make genetic gains of 5 percent, but indications at this point are that gains are in the 10- to 15-percent range.

Agricultural forestry is not such a far-out concept. In the South we are only a step away, and most of the tree improvement work is confined to lands that are intensely managed and cultured. Historically, much of the present acreage devoted to forestry was agricultural land that came to us because of past abuse and subsequent abandonment. I am certain we cannot depend on this type of salvation in the future!

In 1966 I made a simple survey of five Central States forest industries asking for remarks for the 5th Central States Tree Improvement Conference. In essence, I asked what the present and potential interest might be for the use of improved planting stock. In a nutshell, the replies followed this vein: We cannot economically justify a tree improvement program because we do not own land or contemplate owning land, and the short tenure of farm ownership negates any tree improvement gains that would accrue when providing improved stock to the small landowner. The price that we are able to pay for wood does not justify the farmer's use of improved planting stock, and we lack the basic silvicultural knowledge to utilize improved planting stock even if the landowner were interested in growing timber. All firms agreed that genetically improved stock would ultimately result in reduced costs to the mill due to the uniformity of raw materials.

For this paper, I resurveyed those same companies — I have nothing encouraging to report now. One is no longer purchasing wood; ecologically induced economic pressures dictated other methods of production using another source of raw material. Essentially, the response is as follows: We have an interest, but not an active one. Corporate policy is not to own land. This rules out any long-term program such as tree breeding or tree improvement because we lose control when improved stock is outplanted on lands not owned by our company. Our lack of enthusiasm in sponsoring the tree improvement program is also due to the fact that there are Forest Service Experiment Stations throughout the country who do this type of research, and also to the economic squeeze.

As an employee of one of those mills in 1966, I made this comment (White 1966): "In addition to and concurrently with the development of superior trees,

increased research is required in the mechanics of site preparation, planting, and the culture of trees. The improved stock will be of little value if we do not know how to, or cannot afford to, plant and care for it." My remarks then hold for today — tree improvement must be a total program of mechanics, biology, and economics if it is to be accepted and utilized. As Webb (1972) has pointed out, "Do not expect selection and breeding to make up for poor nursery management, poor seedling handling, and poor planting methods."

To summarize, tree improvement and tree breeding will be utilized by industry when they can be economically justified (don't call us, we'll call you). They will be utilized when raw materials are in such short supply that there is no other recourse (crisis oriented), when landownerships are sufficiently large (not too large) for intensive management, when large-scale planting is the norm rather than the exception, or lastly, if and when sociological and ecological pressures give us no other alternative (help us, what do we do now?!). The surveys I have made and the comments I have heard from others indicate to me that this will be the pattern for the development of a tree-improvement program. Until refined forestry practices are necessary in any given area, the people involved in tree breeding and tree improvement can make the greatest contribution by developing a complete program of applied and basic research that can be implemented when the call comes. A research program must start with the nursery and seed source and proceed through the final crop, always stressing the economic values to be gained. Sell the top management on the merits of tree improvement and work intimately with the field forester. His understanding and acceptance of research activities are necessary to the implementation of research findings. Studies that approach operational size will minimize the stigma attached to the greenhouse and pot culture, looked upon by many field foresters as being entirely impractical and therefore nonoperational.

I would hope that these comments and observations, although rather bleak, will offer you some guidelines for the development of meaningful tree-improvement programs acceptable to the industry.

To conclude, I would like to quote from a letter I recently received from Dr. Bruce Zobel:

"The major change in the attitude of tree-improvement programs has been the switch in the attitude of tree improvement as a research effort to an operational level. Now all members

of the cooperatives put it on the level with site preparation, nursery operations, or planting; it is purely operational. Economically, it has been shown to be one of the best investments in forestry operations.

"The theme of our co-ops has been industry participation. Instead of their giving us the money and having us do the work, we ask only for enough funds to do guidance and analysis and the members do the work. This way they feel a proprietary attitude about what is done and they look upon the activities as "our program" rather than "the" or "a" program. If someone has to go out and beg the industry to support a program, it is certain to fail. The need and the enthusiasm must come from the members of the co-op."

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# INCREASED WOOD-FIBER PRODUCTION: TECHNOLOGY, ECONOMICS, AND ECOLOGY

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Forest tree improvement is a form of technological change, and it should be viewed as such. The economic objective of technological change is to increase productivity per dollar invested. This is accomplished through selection and breeding for increased growth rates or reduced losses to insects and disease. Programs which yield improved planting stock make forest investments more profitable by reducing initial costs. The empirical evidence to date (e.g., Davis 1967, Lundgren and King 1965) indicates that investments in forest tree improvement can and do pay off, sometimes rather well.

Along with economic objectives, other goals may be achieved through tree improvement. The improvement of ornamentals, particularly in terms of resistance to pests and the rigors of urban environments, leads to increased amenity values. Even this sort of goal may have economic overtures, however, because of social costs for tree removal and changes in property values associated with tree losses.

## ECONOMIC ANALYSIS

The analysis of economic benefits and costs follows a well established procedure (Marty *et al.* 1966). The changes in cash flows attributable to a tree improvement program must be estimated, then discounted to the present. A comparison with the investment cost will establish if the program is viable — i.e., benefits at least equal to costs. A comparison with other alternatives will establish the relative priority of tree improvement investments. More sophisticated analyses will consider alternative silvicultural packages of fertilization, weed control, tree improvement, and so forth to search out the optimal combination and intensity of practices.

Uncertainty can be incorporated into such analyses. It is possible, using data such as Lester and Burr (1965) published to design selection and breeding systems that virtually guarantee success. If the costs of such a program are not justified, then incremental analyses can suggest at what point the increase in benefits from reduced uncertainty in a tree improvement program just balances costs. Although operationally useful, a yet broader integration of uncertainty may be of greater long-term use when contemplating a technological change such as a tree improvement program.

## TECHNOLOGICAL CHANGE

Our perception of technological change has changed rapidly. A McIntire-Stennis project was established at the University of Wisconsin in 1966 titled "The Causes and Effects of Technological Change in the Forest Industries" (Bentley 1970). The economic viewpoint focused on the role of technological change in the growth and development of national economies. Definition and measurement dominated many research discussions. Unemployment was the dominant social issue, aside from an occasional prophet of environmental doom. All this has been changed by the rapid growth of environmental awareness. Technology no longer is viewed as predominantly beneficial, and many bad side-effects — externalities or costs that are incident on society as a whole — are commonly identified. Many scholarly and popular treatments of these issues, such as Toffler's *Future Shock* (Toffler 1971), have appeared in recent months. The rate of change, scale of impacts, and often unexpected biological and social side-effects give hysterical cries of "ecocide" some credence.

Technological change is the logical outcome of rationalizing man's productive activities. Industrialization, notes Boulding (1964), began with the "turnip."

When agricultural man began to develop crop cultures and plant and animal breeds, and to evolve patterns of rational husbandry, he laid the foundations for industrial man. Later, the harness of energy (mainly coal) provided the major breakthrough for the rational systems of industrial production in the modern world. Forestry has been a part of this phenomenon. For example, changes in mill technology from pitsaw to the modern, all-electric gang saw are illustrative of the general industrialization of developed nations.

Silviculture has been slower to move beyond primitive stages. The general environment was not conducive to change because excess natural raw material, especially in North America, generated low unit values for wood fiber. Long rotations have precluded the rational research and development that took place with hybrids and other rapid advances. A further difficulty faced by the tree improvement people is that breeding for higher wood production is not as easily accomplished as breeding for higher grain production.

We can expect increased interest in intensive silvicultural systems as wood fiber becomes more scarce, causing unit values and the cost of scarce inputs, especially land, to rise. I think there will be a premium on space for timber growing as primary use because of increased demand for recreation lands. As general and specific knowledge increases, more complex systems can be developed at lower costs.

One view on intensive silvicultural systems with which I am familiar was developed by Gordon and Bentley (1970) at the 1969 Wisconsin Forestry Colloquium. Following through their points, we first can note three principles of rational silviculture:

1. Yield is determined by quantity and distribution of photosynthate, and yield is increased by manipulation of these factors.
2. Yield increases require investments, and, other things being equal, the shorter the rotation, the better.
3. Flexibility is always desirable.

In a similar vein, four principles of rational applied research were proposed:

1. Applied research is planned today to yield information in the future. Therefore, the problems that research is designed to solve must be problems of the future.

2. The future is uncertain. Therefore, applied research must be oriented toward producing results with built-in flexibility (breadth of applicability).

3. Applied research must be coupled in real time to productive systems, to provide useful feedback from practice to research. More simply said, research must be goal-oriented, and the goal must be a production goal (e.g., profits).

4. In this technological age, the productive system must be predicted at least in part upon the capabilities of applied research to aid it.

These principles were combined into the following conclusions:

1. Short rotations are necessary to reduce capital carrying costs, allow research results to lead to rapid results in the field, and provide frequent opportunity for change in land use.

2. Intensive care of dense stands will enable rapid vegetative coverage of the site, and maximum photosynthetic activity with fertilization, pest control, breeding, mechanical planting, harvesting, etc. to avoid biological or technological bottlenecks.

Achievement of this type of system, we concluded, will require a research team approach with a systems viewpoint. As almost an afterthought, perhaps prompted by our declaration of a systems view, we have the following paragraph of warning:

Another point should be made regarding a systems approach to more rational silviculture. Agriculture has not done a very able job in recognizing the adverse effects of its rationality. Some of these, such as site deterioration through intensive fertilization, watering, and cultivation, directly affect the producer. Other effects, particularly those associated with monocultures (hard pesticides, for example), may have greater social costs than private costs. A true systems viewpoint will perceive and incorporate these difficulties as well as the more pleasant and profitable advantages of modern plant culture.

## FOREST MANAGEMENT

These ideas, together with a definition of the forest management process, lead to an important conclusion. The processes of management are:

1. *Perception*. — The problem-finding step — being aware that a problem exists and what it is.

2. *Planning*. — Specification of the problem for analytical purposes, information gathering and analysis, evaluation and decision — the problem-solving step.

3. *Implementation*. — On-the-ground activities to carry out planned decisions — the *administrative* step.

4. *Feedback*. — An ongoing step that relates all other steps. It is especially important if new perceptions of problems are to be an improvement over previous problem conceptions. Feedback is a dynamic activity, and it is antithetical to an equilibrium view of the world — economically or ecologically.

Most researchers specialize in the analytical component of problem solving. There has been a conflict between analytical problem-solvers and land managers for some time (Macon 1967). Planners think problems are solved by evaluation and decision; implementers recognize that nothing is changed until activities are accomplished. Feedback mechanisms often are bad — fire control is the only forest activity with a highly developed feedback learning mechanism — and effective learning devices should be built into all planning-implementation systems. It is in problem perception, however, that we are the weakest. Perhaps it would be better to describe this weakness as the most incomplete step in forest management.

## PROBLEM PERCEPTION

If our understanding of problems is weak, too often we solve the wrong problem, then implement the wrong solution, and follow up with a weak feedback mechanism that does not identify our basic mistakes in perception. We need a broader viewpoint than industrial rationality to resolve this difficulty. The principles that Ferkness (1969) recently outlined provide the basis for going beyond industrial man to a philosophy of "Technological Man" — really "Ecological Man." These points are really an ecological viewpoint composed of three interrelated ideas:

1. *Naturalism*. — Man and his management of the forest resource as an integral part of nature — emphasis on natural, not physical complexity.

2. *Holism*. — The systems viewpoint (as contrasted with systems analysis) that all components of a system are interrelated and only have meaning in context of each other.

3. *Internal self-determinism*. — Focus on internal creation of the system — the forest ecosystem with man included — rather than external, usual unexplained forces creating the system.

With this broader perspective of "Ecological Man," we can construct silvicultural systems, including needed tree improvement programs, which are *ecologically* and *economically* sound. To take a few problem areas, we must be concerned with:

1. *Genetic changes*, especially a narrowing of gene pool. How might such changes affect ability to resist much more rapid population processes in pathogens and insects?

2. *Ecology of artificial monocultures*, including effects of fertilizer, pesticides in nutrient and biochemical cycles.

3. *Is the intensive forest flexible*, as we suggest, in terms of real human wants, or is the more "natural" forest sounder?

Answering such questions might lead us to conclude that medium intensity management may in fact be superior for agriculture and silviculture. Such systems would have fewer negative externalities — i.e., pesticides, mineral leaching — and would have more positive externalities — e.g., amenities, ecological diversity.

Consideration of such issues does not mean capitulation to the current environmental evangelism — especially voices that reflect naive or erroneous understanding of forest ecology and economics. It will contribute to the development of sounder strategies for maintaining or improving all qualitative aspects of our life. A broad perspective, while yielding more complex problem concepts, will lead us to attack and solve the real problems. A narrower view of forest production will defeat current timber production efforts because of uncertainty about what facts and opinions we will face in the future. Economics and ecology are, in fact, quite compatible — the discounted value of an ecological disaster, even if it is in the distant future, still is a high present cost to contemplate when designing a rational, but narrowly conceived silvicultural system.

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# INFORMAL GROUP DISCUSSION

*Editor's note:* The morning's presentations were discussed during the afternoon by three groups, each group discussing one of the morning's three topics. Summaries of the discussions, prepared by the discussion leaders, follow.

## TOPIC I

### **What can we achieve through tree improvement?**

(Papers by J. W. Wright and Robert E. Farmer.) Discussion Leader, Hans Nienstaedt, North Central Forest Experiment Station, USDA Forest Service, Rhineland, Wisconsin.

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The discussion not only considered what can be achieved through tree improvement, but also how the results of tree improvement can be put into use. The following questions were raised: Is industry ready and willing to use the information now available? Have tree breeders been too reluctant to make recommendations involving a moment of risk? Do tree breeders have to bear the entire burden of testing prior to release of improved types? How do we mass-produce improved seed?

A strong undercurrent in the discussion was the feeling that genetic researchers and tree breeders, on one hand, and the practicing foresters, on the other, have failed to communicate. Researchers and breeders have been "ultraconservative" and have qualified results and recommendations to such a degree that the man in the field has turned away with the attitude, "He has nothing now, I'll come back later when something has turned up!"

It has been stated that if the plant breeder strives for perfection, he will never develop a usable product. The breeder must be willing to take risks, perhaps like the weatherman — stating the risk as a probability. Industry representatives participating in the discussion indicated that their management would be willing to assume the risks involved. It was emphasized that without taking risks, we would, in fact, achieve a certainty — *the certainty of no improvement*.

If forest managers have questioned the credibility of tree breeders, the breeders have at times reciprocated

when viewing the activities of forest managers. It was pointed out that foresters engaged in seed procurement and seedling distribution not infrequently jeopardize their own programs by ignoring common knowledge regarding the adaptation of seed sources and seed zoning.

The breeders of crop plants rely on the farmers for much of their testing in production situations. Tree breeders should do the same and would find industry willing to cooperate. But this will require advanced planning. The time to plan with industry is when the test is seeded in the nursery, not 2 to 4 years later when material is ready for field planting.

Methods of reducing risks when outplanting partially tested improved material was also discussed. One approach is to develop reliable predictors of growth. Work is now in progress on potential predictors such as isoenzymes, DNA, other constituents of the plants, and defined processes of growth. An understanding of growth components may not only lead to the development of reliable predictors and reduced risks, but may lead to greater growth gains through breeding for specific combinations of growth components. Another suggested way of reducing risks would be to increase the number of species planted. Rather than relying on the potential improvement of one species, several promising products of tree improvement involving a number of species could be planted. This approach, particularly, would require cooperative tree improvement efforts, because it is doubtful that one company would have the funds for breeding programs involving more than one or two species.

In the past, tests of genetic material have essentially consisted of wildland plantings; they have involved a minimum of ground preparation and subsequent control of competing vegetation, and standard spacing such as 6 by 6 or 8 by 8 feet. Future silvicultural practices will, undoubtedly, be more intensive. They may involve more thorough ground preparation and control of competing vegetation, the application of fertilizer, and

## TOPIC II

spacings that will facilitate mechanized harvesting. The goal will be greater production per acre and shorter rotations. It was suggested that tree breeders, in their tests, should use the plantation management practices in the future. However, one participant pointed out that in the majority of tests conducted so far, genotype x environment interactions have been of a type that would indicate that genotypes good on one site would be good on all sites. In other words, the genotypes that are good under the present intensity of management would also be good under the management practices of the future. Be this as it may, it would be desirable to demonstrate through our genetics testing the degree to which improved material can increase production under optimized growing conditions.

Mass production of improved seed was discussed at length. It was emphasized that research costs in the region have almost exclusively been borne by the public, because research has been carried out by universities and federal organizations. Mass production of the improved material for commercial use generally is not the responsibility of the research organizations. It will require developmental programs. The question is — who will be responsible for the organization and funding of such programs?

Industry representatives in the audience indicated that industry is ready to become involved either independently or through cooperative efforts. It was also suggested that the State departments of natural resources would be in a particularly favorable position to organize such programs, and would be able to obtain federal financing.

In summary, the discussion emphasized the following:

1. Tree breeding only becomes meaningful when mass-produced stock becomes available for commercial plantings.
2. Geneticists and tree breeders have preliminary information for several species and the information should be put to use now. Some risks would be involved in using this material.
3. Industry is willing to assume these risks, and some industries are definitely willing to get started now.
4. Mass production of improved material will require cooperation involving Federal, State, and private agencies.

**What does industry need that tree improvement can provide?** (Papers by J. W. Macon and R. B. Valley.) Discussion Leader, Dean W. Einspahr, Institute of Paper Chemistry, Appleton, Wisconsin.

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The discussion leader briefly reviewed the views of the two speakers and pointed out that John Macon had presented his views on current and future use of conifers in relation to the current and future conifer inventory of the Lake States Region. He expressed concern regarding our ability to meet future pine fiber requirements and indicated the need for forest genetic programs that stressed: (1) improved growth rate, (2) improved wood quality, and (3) the need for species that respond to fertilization and irrigation and other intensive forest management practices and, (4) a maximum amount of cooperation between research and management.

Dick Valley, on the other hand, expressed the need for hardwood species that: (1) plant easily, (2) are well adapted to all environments, (3) have rapid cellulose production rates, (4) are compatible with low cost harvesting systems, and (5) have low bark adhesion, easy pulping, and longer fiber structure.

Dr. Valley, like John Macon, stressed the need for cooperation between forest geneticists, forest managers and mill managers in order that a satisfactory "complete" system be developed.

Following the summary, the groups were asked for "feedback" regarding their views on the topic. Bill Bromley (American Pulpwood Association) led off the discussion with a word of caution in which he stated that he hoped the forest geneticist would not go overboard and stress short rotation materials to the exclusion of other types of forest products. Bill expressed the need for everyone involved to consider the "multiple use of wood as well as a multiple use of land." Dick Valley, in defense of his comments in the morning session regarding intensive management-complete tree harvesting systems, indicated he did not feel that such a system could be used on all lands but instead felt that approximately one-third of the land area would be used primarily for recreation, one-third managed using conventional forest management techniques, and that the intensive management system approach would

be confined to those areas near the mill best suited for such an approach.

Dave Dawson, in expressing his views on the intensive management subject, pointed out that intensive management of certain areas would free other areas for alternative uses. Intensive management, Dave felt, should be viewed as a supplement to multiple-use rather than as a deterrent.

Mr. Gordon Connor and Fred Ziemann expressed similar points of view and suggested that we should be genetically improving species for future production systems but, more importantly, we should be getting the most we can out of our present forests by improved utilization (chipping tops, etc.) and through fertilization of hardwood stands. Total tree harvesting systems were discussed and the point was made that should these harvesting methods become accepted, proper consideration must be given to how we plan to revegetate these areas. Mrs. Gordon Connor stressed the importance of educating the public regarding the point that good forest management is good forestry and good conservation.

Hans van Buijtenen and others including Mark Holst and Fred Ziemann expressed the concern that because of the time lag involved (as much as 40 years) in genetic improvement, paper industry needs could easily change before appropriate gains were obtained. A discussion of this aspect of tree improvement indicated that the key to the problem was to build a reasonable amount of flexibility into any genetics program so that the trees being developed could be used for other purposes (sawtimber, ornamentals, etc.) should industry needs change.

Tom Rausch and Clyde Hunt commented that progress in the Lake States Region was not as slow as the discussion might indicate. Tom indicated that the State of Wisconsin was presently using results of genetic studies to determine regions from which they should purchase spruce seed for nursery production. Also, Tom indicated that red pine seed production areas had been established and red pine seedling seed orchards were being developed by the State of Wisconsin in cooperation with the University of Wisconsin. Clyde Hunt commented that we are beginning to recognize the requirements of the type of tree that is needed to make the total tree system work. He also felt that we presently have genetically improved materials that meet the requirements and all we need to do now is to plug these materials into the system. Clyde stressed the use of *Populus* species, and the use of a mixture

of clones; he commented that aspen, because of its flexibility (usefulness in recreation, lumber, and pulp), its site requirements, and growth habit, could be expected to work well in "the system." Jim Hensel along with the discussion leader commented further on the "total tree concept," stressing the need for demonstrating what our presently available improved materials can do on the areas being harvested via the total tree concept.

From the group came the comment that we have been working in forest genetics in the Lake States Region for a considerable time period, and what we now need are action programs to make genetically superior seed and seedlings available to industry and the public. Another comment from the floor referred to John Macon's concern about the low specific gravity of balsam fir. The question was raised about the possibility of improving specific gravity and other juvenile wood properties of such species as red pine, jack pine, larch, and balsam fir. Comments from several geneticists who had worked with these species indicate modest gains ( $\pm 10$  percent) could be obtained. Following a rather lengthy discussion on improvement of juvenile wood characteristics, Clyde Hunt, John Macon, Dick Valley, and Hans van Buijtenen reviewed the problem of what fiber characteristics are wanted by the papermaker. It was pointed out that the fiber characteristics desired depend upon the end-product requirement, and that to produce the variety of products now being manufactured by the paper industry, anywhere from six to 30 basic fiber types would be required. It was pointed out, however, that by separating springwood from summerwood and/or mature wood from juvenile wood, more than one fiber type could be obtained from the same tree.

Dick Valley discussed the importance of fiber characteristics to end-product properties and production speed, and it was concluded that fiber properties (fiber length, flexibility, etc.) should be considered for improvement both by genetic and silvicultural techniques. Tom Rudolph, among others, emphasized the need for producing trees that will give greater volumes of wood per acre; as far as wood quality is concerned, perhaps the most important contributions that could be made would be to give the papermaker a uniform quality raw material with certain well-defined properties that would then allow him to optimize pulping and papermaking conditions.

Tom Rudolph reemphasized the comments of several of the symposium speakers who indicated we need a

balanced approach in which research effort is expended toward both tree improvement and forest management methods to get the improved materials into the field. Tom also felt that in many instances we are not testing our materials under the type of field conditions that they should ultimately be growing under, and that due consideration should be given to this aspect of improved-tree evaluation.

The final topic before adjournment was the difficulty encountered by the various research groups in obtaining adequate funding for tree improvement and testing of improved materials. Holst, Garrett, Macon, and Einspahr each commented regarding funding problems, particularly as they pertained to the Lake States Region and the Northeast. Lack of adequate funding was of primary concern. The North Carolina State Cooperative program was described as a good one which has the desired flexibility. It was pointed out, however, that company size, forestry staff, and land-holding patterns in the North and Northeast differ from those in the South, and that some type of cooperative program in which several companies pool their resources to produce improved seed and seedlings would be more appropriate.

The discussion of the topic "What does industry need that tree improvement can provide?" stressed the following needs:

1. Action programs that provide adequate numbers of improved materials for the public and industry.
2. Rapid-growing hardwoods and conifers that have been tested for site requirements.
3. Continued emphasis on improvement of hardwood fiber properties.
4. Increased emphasis on improving the juvenile wood characteristics of tree species, particularly conifers.
5. Forest genetics research programs with built-in flexibility so that as paper industry needs change, the materials involved will still be useful.
6. Balanced programs that not only provide improved trees, but the "know-how" to establish and manage these improved materials.
7. Trees that are well adapted to future highly mechanized harvesting systems and that fit into the

"complete system," which considers establishment, growth, harvesting, and manufacture of the final product.

It was also generally agreed that there is a need to establish lines of communication, cooperation, and feedback between forest geneticists, forest managers, and pulp and paper management so that a suitable overall production system can be developed.

### TOPIC III

**Tree improvement as a forest management supplement.** (Papers by Gordon White and William R. Bentley.) Discussion Leader, J. Douglas Brodie, Department of Forestry, University of Wisconsin, Madison, Wis.

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The session leader introduced the topic with a brief summary of what he, as a nontree breeder, had learned from the morning session. Basically, tree breeding can offer improvement in two broad categories — quantity and quality. In terms of quantity, tree breeding will result in greater growth rates that will benefit forest management in two ways: (1) greater yields per acre, and (2) shorter rotations. The quality dimension can be divided into three parts: (1) the physical properties of the tree that enhance its desirability at the mill, such as fiber, bark, and chemical properties of the wood, (2) the form and stand characteristics and properties of the tree that enhance harvesting, and (3) the growing or tending properties of the tree, including biological resistance, tolerance for adverse site and climatic agents, and pest resistance.

Timber management is a long-term investment activity that is fraught with uncertainty. Initially, attention is likely to be focused on protection or stand improvement in existing stands. Terms such as "intensive management" or "high-yield silviculture" imply not only a systems approach to forest management but also shorter time periods for production, afforestation, and reforestation. Certain experimental maximum fiber production projects in the South have suggested the term agri-forestry. This might suggest that forestry at present, similar to agriculture in the past, may be able to make substantial strides forward through plant breeding.

Professional forestry during the past 70 years, by crying out against the wolf of scarcity, has instituted

substantial gains in fire protection, harvest control, reforestation, and afforestation. Economic scarcity of timber products within the next three decades appears to be a real possibility, without substantial increases in forest productivity during the interim. Such scarcity could be expected to develop sooner in local regions and for particular species. A conference such as the present one addresses itself hopefully to the real possibilities of forest tree improvement and perhaps somewhat ruefully to the seeming inertia in the adoption and application of modern tree breeding techniques in the north-central States.

In discussion the group decided that the production demand for improved tree stock will not be realized until scarcity or incipient scarcity occurs. The demand will appear first in short-rotation, reforestation-oriented operations. It is beginning to be felt in the Lake States now in seed source certification, nursery practices such as culling, and in the establishment of seed orchards. Part of the problem in the Lake States appears to be that the demand for the tree breeder's talents does not seem to be as intense as in other parts of the country, such as the South. Discussion indicated that conditions are different in the Lake States than elsewhere. In the South, the overhead of landownership has provided a spur to efficiency and to the adoption of high-yield management practices, including the application of tree breeding results. Such conditions are currently lacking in the Lake States, and the discussion focused on the question of what tree breeders should be doing while awaiting the development of demand. It was agreed that the Lake States tree breeding establishment had not been, and would not be, idle during this interim. As in the past, they should continue to develop a wide diversity of plant materials and stockpile knowledge and techniques; in the absence of widespread application of results, they might continue to develop and

question the type and extent of future demand for improved trees.

It was agreed that the efforts should not be focused solely on basic research. There is, and will be, a real demand for applied research that will satisfy immediate needs once improved forest plant materials are required. The question was raised as to why Lake States industry found it impossible to support basic tree improvement research. An industry participant replied that interest on the part of industry was great; however, support for tree improvement research was impossible for a number of reasons. At present in the Lake States, growth of trees on industrial land is much greater than the current or prospective rate of drain through harvest. It was stated that if you are planting extensively, then you can use a better tree; if you aren't, you can't.

Attention should also be given to the communication of results that can be used and applied now to stimulate demand for future tree-breeding improvements. One of these techniques for immediate application would be the identification of superior trees for use even under natural regeneration systems. Small improvements spread over large-scale acreages can count significantly. Efforts that must necessarily be based on tree planting will be spread over a much smaller area, at least at present. The importance of the effort going into seed and tree improvement shouldn't be minimized; however, natural regeneration and selection systems should be considered as well. The implied correlation between genotypic and phenotypic characteristics suggested by the application of tree breeding expertise to natural regeneration systems was questioned. Discussion from the floor indicated that while the magnitude of this correlation is generally unknown, it could at least be assumed to be positive; therefore, it is better to apply phenotypic selection in natural systems than no selection whatsoever.

# PRACTICAL BREEDING OF COTTONWOOD IN THE NORTH-CENTRAL REGION<sup>1</sup>

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More than 20 years ago Scott Pauley (1949) designated the genus *Populus* as the "guinea pig of forest-tree breeding." This designation is still appropriate as evidenced by the steady, almost overwhelming, stream of publications related to the genetics and breeding of poplars. A good indication of the scope and depth of genetic work with poplars can be found in the recent review of poplar breeding by Muhle Larsen (1970) and discussions of cottonwood genetics and breeding by Schreiner (1971) and Farmer and Mohn (1970). These reviews cover a variety of research and breeding activities at widely dispersed locations and support the contention that our knowledge of poplar genetics is comparable with that available for any other group of forest trees. My assignment is to relate this knowledge to the "practical" breeding of cottonwood (*Populus deltoides*) in the North-Central Region. While I will concentrate on eastern cottonwood, the biology of the genus *Populus* requires consideration of the other species and hybrids commonly called poplars. Aspens will not be considered.

For a breeding program to qualify as "practical" it must be undertaken with a high probability of producing improved material within a reasonable time. At this meeting Farmer (see page 9) has pointed out the strong evidence of potential for genetic improvement in cottonwood. In addition, the experience of Europeans in poplar breeding (FAO 1958, Muhle Larsen 1970), the progress in poplar hybridization in the Northeast (Schreiner 1949, 1950), and the work with cottonwood in the Lower Mississippi Valley (Farmer and Mohn 1970, Mohn *et al.* 1970) all indicate that we can design programs for this region that will rapidly produce genetically improved poplars (cottonwoods, balsam poplars and their hybrids). While additional genetics work is needed to design optimum

programs, neither a lack of knowledge nor a lack of biological potential is a major stumbling block to the initiation of practical breeding in our region.

"Practical" in breeding implies a use for the product, not just the production of biologically improved material. The reason many forest geneticists in this region take a "guinea pig" approach to work with poplars is that poplars aren't planted extensively enough to justify breeding programs. We can speak about practical breeding of cottonwood at this meeting because our theme is the future and there are strong indications that our future may include a demand for improved poplar planting stock. Poplars can have great value as a crop on the "fiber farms" Westell (1969) foresees developing in this region. They are ideal for use with systems of intensive cultivation on selected sites because: (1) they have the potential for rapid growth essential to making highly mechanized "forest farming" pay, (2) we have the technology for effective utilization of their wood, and (3) a wealth of experience has been acquired that can be used to quickly develop plantation management systems suited to our region.

The development of intensive culture of cottonwood or poplars in this region will probably be centered on some of the 4 million acres of excellent and good quality elm-ash-cottonwood sites Dawson and Pitcher (1970) reported. It can logically be expected to follow a progression from experimental plantings to pilot-scale plantings to commercial plantations such as McKnight (1970) described for the lower Mississippi Valley.

At this time most of the work in the North-Central Region is in the experimental stage. We've been in that stage for a considerable period of time. For example, a 1913 USDA publication includes a photograph of a fine 12-year-old cottonwood plantation in southern Minnesota with trees of pulpwood size (Williamson

<sup>1</sup> Published as Journal Series Paper No. 77652 of the Minnesota Agricultural Experiment Station.

1913). Records of hybrid poplar plantings go back at least to 1888 and other test plantings have been established periodically (Rudolf 1948). Results have been mixed, but encouraging enough to sustain interest.

The next step will be the development of systems for cultivating poplars in our region on a large scale. This means we must define the elements of these systems from planting to utilization and bring them together in a workable package. This task will take the combined efforts of silviculturists, field foresters, utilization specialists, and others. Ironically, in this critical step in the development of viable breeding programs, the role of the forest geneticist is small.

## TESTING COTTONWOOD SELECTIONS AND POPLAR HYBRIDS

The immediate task for forest geneticists is the identification of materials suitable for use in small-scale experimental or demonstration plantings. The goal is to find materials that will perform well; the guideline should be reliability based on sound biological reasoning or past testing. This step is analagous to the delineation of seed collecting zones or seed source recommendations in other species. It is most critical in poplars because a relatively small number of "well-traveled" genotypes, not seedlings of a local origin, have traditionally been used for planting stock. Often these materials are planted because they are available and not because of their performance in local tests.

The task is complicated by the variety of materials available. In our region the native cottonwood can be considered. *Populus balsamifera* is also native to a part of our region and the potential for fiber production under plantation conditions of this species is unknown. In some Minnesota tests *Populus nigra* and *Populus trichocarpa* have grown at impressive rates and these species, along with other exotics, are candidates. Hybridization occurs between many *Populus* species naturally and nearly all can be artificially crossed (Muhle Larsen 1970), adding many hybrids to our list. The complexity of species and hybrids is compounded further by the capacity for asexual propagation common in poplars. Individual genotypes are used on a wide scale and the clone as a unit of genetic identity increases the number of options almost to infinity.

The task of making recommendations becomes manageable when two biological considerations come into play. The first of these is the need to avoid excessive

genetic uniformity. Schreiner (1959) and others have stressed the increased danger of disease and insect attack in monoclonal plantations. To maintain genetic diversity, planting of individual clones should be avoided, and recommendations should only consider mixtures of at least 15 to 20 genotypes. Seedlings can also be used to ensure genetic diversity and this may be the only reasonable alternative when propagation difficulties are encountered.

The second consideration is the need to use materials that are well adapted to the conditions under which they are to be grown. To ignore this factor invites poor growth or excessive injury due to climatic stress, disease, and insects. Because the trees we plant must be adapted to the planting site, our choice will be among materials that have been adequately tested in the locality, and selections from local wild populations.

In some parts of the region work with cottonwood or poplars has progressed to the point where a group of high-quality clones can be identified, but in many areas the results of tests have been negative or inconclusive. There the local wild populations will be the best source of planting stock. Smith (1968) recommended this sort of alternative after reviewing experience in poplar planting in Canada, and Maisenhelder (1970) recommended the use of selections from local populations of cottonwood in the South, after a large array of hybrid materials failed to perform satisfactorily.

Cottonwood is the logical species to plant in most parts of our region. The simplest approach is to collect and use cuttings or seed from good stands. Some sort of phenotypic field selection may be practiced in an effort to get genetic improvements. Such selection should be based on genetic information — e.g., heritability estimates and character correlation — and on a critical assessment of characters to identify those with economic importance. Little information is available concerning the effectiveness of field selection for specific traits. However, traits that are known to be under strong genetic control, such as *Melampusora* rust resistance (Jokela 1966) should be given more weight than traits such as growth, for which the effectiveness of field selection is questionable (Farmer 1970, Mohn and Randall 1969). As a general rule it is best to choose trees that are outstanding for one or two economically important traits and satisfactory in other respects.

The number of trees selected in the field should be adequate to ensure genetic variability in the planting

stock. If the use of selection directly via asexual propagation is anticipated, an excess should be selected because a large proportion of the genotypes will be eliminated in the nursery as a result of propagation difficulties. Muhle Larsen (1970) reported a range in rooting success of cottonwood clones from 0 to 100 percent. Work with cottonwood in Mississippi has been plagued with propagation difficulties, causing Maisenhelder (1970) to recommend restricting field selecting to 3- to 5-year-old trees when developing a source of planting stock.

The procedures used in obtaining stock for immediate planting will vary greatly from locality to locality. Past testing, decisions regarding the best way to propagate, and the resources available will all be determining factors. No matter what procedure is followed, the emphasis always should be on obtaining reliable materials quickly for use in developing effective systems of plantation establishment and management.

## **BREEDING OF POPLARS**

### **Cottonwood Breeding**

Actual breeding will come in response to the demand for improved materials associated with increased planting. In designing breeding programs the first step will be the establishment of clearly defined goals. All aspects of the cultural systems in use, from planting to utilization, should be considered; priorities should be developed so efforts will be concentrated on making changes that have an actual impact on productivity.

Genetic improvement, as in other species, has two phases: (1) the production or definition of populations with which to work and (2) the selection of superior materials from these populations. In developing working populations, the objective is a high frequency of favorable genes or gene combinations.

In practice, materials with which to work can be expected to accumulate with astonishing rapidity. Identification of the superior materials is more difficult and time consuming. Large backlogs of promising, but unproven, materials are characteristic of poplar work. Evaluation in the nursery can be used to cull out material with poor propagation characteristics, susceptibility to pests, or obviously low vigor. However, experience with cottonwood in the South suggests that the most substantial gains will come from selection based on adequate field testing (Mohn and Randall 1969). Emphasis in a practical breeding program should be on

the establishment of such field tests using enough materials to permit the intensive selection necessary to obtain substantial genetic advances.

It is probable that asexual propagation will be used in cultural systems developed for this region and that clonal tests will be the basic tool in genetic evaluation. Clonal tests should be established and maintained using the same cultural techniques as are used in commercial plantations. Testing on several sites will most likely be required (Randall and Mohn 1969) and final selection should be delayed until trees have been tested for a half-rotation (Schreiner 1971). Relatively few ramets per clone are needed. Schreiner (1971) recommended from 10 to 20 per site and this number was adequate in the Stoneville tests.

Concentration on field evaluation means that breeding programs should be designed so several hundred new clones are placed in field clonal tests annually. The acreage required is substantial but can be reduced by establishing an initial test on a single site with a large number of clones, conducting a preliminary evaluation at perhaps one-quarter rotation age, and then testing only the better clones on other sites. The cost of large-scale field testing can also be reduced by other means. In the Forest Service program at Stoneville we were able to place several hundred clones in a field test at a low cost by combining our test with a commercial planting. The arrangement was most satisfactory to the cooperator (who cultivates and maintains the planting) because he will harvest the test along with the rest of his plantation.

In this region I recommend that the first series of clonal tests be aimed at evaluation and selection of clones from local cottonwood populations. This will ensure that materials selected in the early stages of the breeding program are well adapted to local conditions. Phenotypic selection can be used to obtain the candidate clones; but since the emphasis is to be placed on relatively large numbers of clones, its intensity will be relatively low. If the pollarding and nursery propagation techniques described by Schreiner (1971) can be used effectively, selections can be placed in field tests directly. If not, the most practical alternative is the cloning and testing of open-pollinated seedlings from the plus-trees. Materials currently being used as planting stock should be included in these, and all tests, as a basis for comparisons.

The process is a kind of mining of the natural population that should not be carried out indefinitely. The

effectiveness of selection in terms of usable gain per unit effort will decrease as additional materials are tested. A limit should be set and when it is reached the emphasis shifted. A reasonable approach would be to continue establishing tests until 1,000 clones are being evaluated. If the top 5 percent of the clones tested were selected, this phase of the program would yield a group of 50 clones suitable for use in commercial plantings and as a base population for further breeding.

After adequate numbers of local cottonwoods are under test, new populations that have a high probability of containing favorable genotypes should be located or created. Results of provenance tests, such as those coordinated by J. J. Jokela of the University of Illinois, may indicate that nonclonal populations of cottonwood are worth considering. In Minnesota, for example, a high proportion of the exceptional phenotypes in a 6-year-old provenance test are of a Missouri origin. We, in Minnesota, should consider practicing selection in populations obtained from central and northern Missouri if this trend continues.

While work is being carried out with nonlocal populations, selective breeding should be initiated using the best local cottonwood. The same types of procedures employed with seed-propagated species can be used. The first phase will involve the crossing of the best field selection to produce improved populations, screening these populations of progeny in the nursery, and placing the most promising materials in clonal tests. Selecting and mating can be repeated through several generations or discontinued if alternative methods of generating working populations appear more profitable.

## Poplar Species Hybridization

While *Populus deltoides* should serve as a base for improvement in this region, it is improved poplars that really interest us. The whole genus *Populus* should serve as a gene pool for constructing the base populations. Schreiner (1959, 1966) has repeatedly urged this approach. Recently he proposed an ambitious program for obtaining maximum genetic improvement of poplars (Schreiner 1971). Many of the procedures outlined in this scheme, including both intra- and inter-specific hybridization, can be used to develop working populations in our region's long-term improvement programs.

Species and racial hybridization using the best local materials as one parent should also be initiated early in the program. The objective is to produce populations that either express hybrid vigor or combine the favorable traits of two or more *Populus* species. Crossability patterns for species of poplars are fairly well defined and there are some indications of the combinations that produce vigorous offspring (Wright 1962). In a practical breeding program this sort of information should be used to concentrate effort on producing the good combinations. In this region crosses of cottonwood with *Populus nigra* and several of the balsam poplars are good possibilities. Initial crosses should be designed to sample several provenances of the non-local components. Mixtures of pollen from several trees can be obtained from cooperators and used to make these crosses.

In the first stages of hybridization, relatively small numbers of seedlings from each combination should be produced so efforts can be centered on producing more combinations. Results from nursery or short-term tests of these materials should be used as a basis for planning additional hybridization. Exceptional phenotypes from the hybrid population should be placed in clonal tests that permit their evaluation relative to the best local cottonwood.

In addition to recurrent selection schemes and hybridization, less conventional techniques, such as the production of polyploids, may be employed in the production of better populations from which to select. No matter what techniques are used to generate materials, practical breeding programs should be aimed at continuous improvement of planting stock through intensive selection. This can be achieved most effectively through field testing of large numbers of clones.

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# MINIMAL APPROACHES TO GENETIC IMPROVEMENT OF GROWTH RATES IN WHITE SPRUCE<sup>1</sup>

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## WHAT CAN BE DONE?

Several features of central importance to genetic improvement of white spruce have been demonstrated by tree breeders. First, white spruce is genetically a highly variable species and much of the existent variation can be readily incorporated in planting stock (Jeffers 1969, Holst and Teich 1969). Second, local seed often is not the best for rapid growth (Nienstaedt 1969). Third, certain stands in southeastern Ontario (Ottawa River Valley) have demonstrated genetic potential for relatively rapid growth over a wide geographic range, including the Lake States (Nienstaedt and Teich 1972). Some of the stands from which genetically superior seed has come are still present and it seems likely that other stands in the Valley will be shown to possess genetic superiority in growth potential. Fourth, the consistently superior growth of certain Ontario seedlots when grown from North Dakota to New Brunswick suggest that one or at most a very few seed orchards could provide improved seed for a geographic region such as the Lake States.

If genetic improvement of white spruce is thus clearly possible, how much improvement might be anticipated? Improvement predictions depend on the improvement methods chosen and on reliable estimates of the complex reactions between trees and their environment. For the simple improvement methods discussed here, namely transfer of seed or sources of seed, research results suggest that seedlings grown from tested southeastern Ontario seed will be 15 percent taller than comparable seedlings from local seed sources in the Lake States (Nienstaedt and Teich 1972). Given that

taller trees generally have larger diameters, the potential for increasing wood production is substantial.

## HOW TO DO IT

If artificial regeneration of white spruce were a large factor in the Lake States forest economy, a full-scale program of selection and breeding would probably be justified in terms of cost-benefit analysis; then the necessary additional personnel, supplies, etc. could be recommended. The following schemes, however, assume that the improvement program must be carried out as a part of existing nursery operations, but with minimum commitment of effort, supplies, or skills beyond those normally available. Emphasis is placed on minimal approaches due to the uncertain position of white spruce in reforestation efforts in the Lake States and due to the improbability of substantial expansion of tree breeding efforts. A prominent feature of the improvement potential in white spruce is the high probability that such minimal approaches will result in worthwhile yield increases.

In presenting three possible approaches, the following assumptions are made:

	<i>Assumption</i>
Biological:	
Seed harvest	Every fourth year
Plantable seedling yield	135,000/bushel of cones or pound of seed (10 per- cent inviable, 20 percent nursery cull)
Annual seedling requirements	2,000,000
Commercial cone bearing age:	
Grafts	10 years
Seedlings	30 years

<sup>1</sup> Research supported by the College of Agricultural and Life Sciences, University of Wisconsin, Madison, and by the Wisconsin Department of Natural Resources.

## Economic:

### Labor costs:

Propagator	\$30/day
Laborer	\$20/day

### Purchase costs:

Canadian seed	\$40/pound
Local seed	\$10/pound
Local cones	\$8/bushel
Orchard cones	\$10/bushel
Orchard seed	\$12/pound
Interest on investment	5 percent

The goal of 2 million seedlings annually represents present nursery production in Wisconsin. This goal could be expanded if a regional program was considered or contracted for lesser production needs, although tree improvement efforts beyond direct seed purchase would become financially and administratively unattractive at low levels of nursery production. The biological assumptions are based on published silvical information about white spruce. Cost assumptions represent current wage and price estimates. Compound interest factors were applied to establishment and maintenance costs throughout the life of the orchard. Seed purchase and collection costs were compounded only for the interval between seed acquisition and seedling distribution, a period ranging from 4 to 7 years in each purchase or collection cycle.

## Direct Seed Purchase

Seed source experiments have demonstrated improved genetic growth potential in southeastern Ontario white spruce stands. At our present level of knowledge, seed purchase probably should be restricted to tested stands or stands on comparable soil types in the immediate vicinity.

Limited purchase arrangements for source-certified seed seem possible, although none have been successfully completed as far as I know. A Canadian consulting forester last year expressed interest in filling a seed purchase request from the Wisconsin Department of Natural Resources,<sup>2</sup> but the seed crop was too light to warrant commercial collection. This year, spruce budworm attacks have prevented development of a commercial cone crop<sup>3</sup> in the stands of interest.

<sup>2</sup> Personal correspondence with W. Brenner, Wisconsin Department of Natural Resources.

<sup>3</sup> Personal correspondence June 23, 1971, from Dr. E. K. Morgenstern, Canadian Forestry Service.

An approximate economic analysis of direct seed purchase is shown in table 1. The estimated seed cost is calculated from cone picking costs on standing trees (Pitcher 1965) plus 40 percent (20 percent inflation, 20 percent profit). The seed purchase cost of \$2,400 is divided into four amounts of \$600 each, representing an annual seed sowing rate of 15 pounds. Interest rates were applied to the period from seed collection to seedling distribution. Each 4-year cycle of direct seed purchase represents an added cost of about 28 cents per thousand plantable seedlings. Administrative simplicity, low cost, and minimum time to produce superior planting stock are the principal positive features of direct seed purchase. Uncertainty of seed availability is the main disadvantage. Seed availability will be subject to major biological uncertainties; also, increased interest in source-certified seed may require seed collection controls by Federal or Provincial governments in Canada to prevent degradation of an important natural resource. Moreover, several stands of interest are privately owned and maintenance of accessibility or even existence of such stands is uncertain.

Table 1. — Cost analysis of direct seed purchase

Year	Activity	Improved seedlings direct cost	Unimproved seedlings direct cost
		Dollars	Dollars
0	Purchase and sow seeds	600	150
1	Sow seeds	600	150
2	Sow seeds	600	150
3	Distribute seedlings and sow seeds	600	150
4	Distribute seedlings	--	--
5	Distribute seedlings	--	--
6	Last improved seedlings distributed	--	--
Total cash cost		2,400	600
Total improved seed cost \$2,400 cash plus \$600 interest = \$3,000			
Total unimproved seed cost \$600 cash plus \$150 interest = 750			
Added cost of improved seed		\$2,250	
Seedlings produced = 8,000,000			
Added cost per thousand = \$0.281			

## Grafted Seed Orchard

If regular seed purchase in Canada proves inadequate it may be necessary to move the source of seed to the Lake States. A grafted seed orchard will accomplish the move.

The project analysis (table 2) shows a more complicated program in which the part-time employment, training, or assignment of a plant propagator would be necessary. One cost, as indicated by brackets in the table, perhaps might be omitted. As more plant material from southeastern Ontario is collected and brought to the Lake States, scions may be available free of charge. At least two research organizations, the University of Wisconsin and the Institute of Forest Genetics, are starting graft collections of white spruce from southeastern Ontario. Although a grafted seed orchard will remove some of the uncertainties associated with direct seed purchase, comparing table 1 with table 2 shows that the grafted seed orchard will have the disadvantages of increased investment cost, slightly greater cost per thousand seedlings produced, and a doubled time period between initiation of the project and actual production of genetically improved seed.

Table 2. — *Cost analysis of grafted seed orchard*

Year	Activity	Direct cost
		Dollars
0	Scion collection, grafting	(350) + 600
1	Grafting	600
2	Graft maintenance	150
3	Site preparation, field planting of grafts	200
4-9	Orchard maintenance	<u>1/</u> 240
10	Seed collection (cones picked from standing trees)	720
14	Seed collection (cones picked from standing trees)	720
18	Seed collection (cones picked from orchard thinnings)	720
22	Seed collection (cones picked from orchard thinnings)	720
26	Seed collection (cones picked from topped trees)	720
30	Seed collection (cones picked from topped trees)	720
34	Seed collection (cones picked from topped trees)	720
41	Last improved seedlings distributed	--
Total cash cost		7,180
Total grafts 3,000 (15 acres)		
Total improved seed cost \$7,180 cash plus \$14,195 interest		= \$21,375
Total unimproved seed cost \$4,200 cash plus \$1,260 interest		= <u>5,460</u>
Added cost of improved seed		\$15,915
Seedlings produced = 56,000,000		
Added cost per thousand \$0.284		

1/ \$40 per year.

## Seedling Seed Orchard

Establishment of a Canadian seed supply in the Lake States could be achieved in another way. By

obtaining as little as an ounce of seed from one of the tested stands, a seedling seed orchard could be established. The principal capital cost would be in weed control to insure survival, rapid growth, and reasonably early flowering (table 3). Total capital costs would be very low and added cost per thousand seedlings would be lowest of the alternatives presented. Added cost would further decline if the orchard were continued beyond 41 years. The main disadvantage to a seedling approach is the time lag between initiation of the project and production of commercial quantities of improved seed. It might be that loss of growth potential in plantations established during the 15 to 25 years of a lag time would far exceed the higher initial costs of quicker methods.

Table 3. — *Cost analysis of seedling seed orchard*

Year :	Activity	Direct cost
		Dollars
0	Seed purchase and sowing	20
3	Site preparation and planting	140
5-10	Plantation maintenance	<u>1/</u> 240
30	Seed collection (cones picked from orchard thinning)	720
34	Seed collection (cones picked from orchard thinning)	720
41	Last improved seedlings delivered	--
Total cash cost		1,840
Total seed trees = 3,000 (15 acres)		
Total improved seed cost \$1,840 cash plus \$2,328 interest		= \$4,168
Total unimproved seed cost \$1,200 cash plus \$360 interest		= <u>\$1,560</u>
Added cost of improved seed		\$2,608
Seedlings produced 16,000,000		
Added cost per thousand \$0.163		
<u>1/</u> \$40		

## COST-BENEFIT ANALYSIS

The economic implications of estimated added seedling cost for genetic improvement are summarized in table 4. Assuming a planting rate of 1,000 trees per acre, a rotation age of 75 years, and required investment return of 5 percent, added costs for the three improvement approaches range from \$6.32 per acre for a seedling seed orchard to \$11.01 per acre for the grafted seed orchard. A pulpwood productivity of 35 cords per acre (Wilde *et al.* 1965) and a current stumpage price of \$7.50 per cord (Peterson 1970) produce a projected market value of \$262.50 per acre. Added

Table 4. — *Cost benefit analysis of improvement costs at rotation age*

Improvement method	Estimated added	Estimated value of:	Growth
	improvement cost:	unimproved wood	improvement
	per acre	per acre	required
	Dollars	Dollars	Percent
Direct seed purchase	10.90	262.50	4.2
Grafted seed orchard	11.01	262.50	4.2
Seedling seed orchard	6.32	262.50	2.4

costs for genetic improvement thus range from 2.4 percent to 4.2 percent of estimated wood value. The anticipated benefits of a volume growth increase in excess of 15 percent compare very favorably with estimated costs of achieving the growth increase.

## WHAT HAPPENS NEXT?

In the case of white spruce, tree breeders have accomplished exactly what is expected of them. The pattern of geographic variation has been determined, at least in rough outline, and sources of potentially superior seed have been identified. Genetic improvement of white spruce is clearly biologically feasible and techniques for achieving the improvement are well developed. In addition, simple cost-benefit analyses indicate the economic feasibility of producing genetically improved white spruce planting stock.

With feasibility studies accomplished, the decision to produce genetically improved seedlings rests largely on how one views the future of planted white spruce in the forest economy of the Lake States. The Federal government obviously views planted white spruce as an important element, and is proceeding with an intensive tree improvement effort.<sup>4</sup> The views of State governments and private industry are less clear. State forest nursery production seems to have stabilized after a period of rapid decline following changes in federally supported land management programs. An annual production of at least 5 million white spruce seedlings in the Lake States seems reasonable for the next several years: 1 million in Michigan,<sup>5</sup> and 2 million each in Minnesota<sup>6</sup> and Wisconsin (Wisconsin

Department of Natural Resources 1970). Distribution of State nursery stock varies between States with about 60 percent of the Minnesota production<sup>6</sup> and about 30 percent of the Wisconsin production going to State and county lands (Wisconsin Department of Natural Resources 1970). States thus have an important stake in white spruce improvement. Most of the remaining trees produced by State forest nurseries go to private owners of small acreages. It is doubtful that genetic improvement in growth rate has much significance for the latter group. Forest industry similarly would seem to have little direct need for improved white spruce in view of the relatively small planting programs of most companies.

Exploitation of research findings on white spruce by State governments in the Lake States seems to be proceeding only in Wisconsin, where initial attempts for direct seed purchase, plus plans for a grafted seed orchard with production objective of 2 million seedlings annually are in progress. A joint improvement effort among the States would seem feasible. It has been estimated that a program for direct purchase of source-certified seed could be organized at a level of 5 to 10 million seeds in good seed years.<sup>2</sup> A program at this level would meet about 30 percent of annual State nursery production in the Lake States. A grafted seed orchard program designed to meet a regional demand of 5 million seedlings annually would require about 8,000 grafts and 40 acres of land. Within 5 years a program of this size could be established.

## POSTSCRIPT

Discussion following presentation of this paper brought out two points of further importance. First, the choice of 5 percent as a compound interest rate may be low for industrial cost-benefit analysis, though not necessarily low for public land management. The results of cost-benefit analysis for the proposed methods show such wide margins for benefit that substantial changes in direct cost or interest rate could be accom-

<sup>4</sup> *Personal correspondence in August 1971 with R. Miller, Region 9, USDA Forest Service.*

<sup>5</sup> *Personal correspondence in August 1971 with J. Hodge, Michigan Department of Natural Resources.*

<sup>6</sup> *Personal correspondence in June 1971 with E. Kurki, Minnesota Department of Natural Resources.*

modated without altering the conclusion that genetic improvement in white spruce is economically attractive. Second, not all white spruce seedlings planted in the Lake States need to be from genetically superior seed. Seed needs could be met more cheaply if genetically superior seed was mixed with local seed. Most of the merchantable crop will be in the genetically superior trees, while inferior material will be removed by mortality through suppression, early thinnings, or Christmas tree harvest.

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# PRACTICAL BREEDING PROGRAMS FOR JACK PINE IN THE LAKE STATES

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Jack pine (*Pinus banksiana* Lamb.) is the most common pine in the Lake States and is expected to play an increasingly important role in Lake States planting programs. This species is easy to plant successfully even on dry, sandy soils. Its rapid growth during the first 30 years makes it suitable for intensive-culture, short-rotation forestry. And it is suitable for kraft process pulping — particularly important because of the expanding kraft mill capacity in the Lake States.

Research on genetic improvement of jack pine has been underway since 1940. Results from these studies have formed the basis for two recently started jack pine seed orchard programs — one in Michigan and one in Minnesota.

This paper briefly summarizes some of the past jack pine studies and proposes a short- and long-term jack pine breeding program for the Lake States.

## HIGHLIGHTS OF PAST RESEARCH

### Seed Source Variation

#### *The Canadian Rangewide Study*

This is the youngest of the jack pine seed source studies and was started by the Canadian Department of Fisheries and Forestry. Seed was collected from 100 natural stands throughout the entire species range and nursery-sown in Canada and Wisconsin in 1962 and in Michigan in 1964. Five permanent test plantings have been established in Michigan, two in Wisconsin, and one in Minnesota.

Early results show that the sources from the three Lake States are the fastest growing in the test plantations; i.e., the seed sources best suited for Minnesota,

Wisconsin and Michigan are to be found within the region.<sup>1,2</sup>

#### *The Cloquet Study*

This is the oldest jack pine seed source study in this country. It was started by the University of Minnesota in 1940; 32 seed sources (22 from the U.S. and 10 from Canada) were planted near Cloquet, Minnesota. As of 1957, results indicated that trees from seed sources located south of the planting site in Pine and Fillmore Counties, Minnesota, grew from 7 to 13 percent faster than the local seed source (Schantz-Hansen and Jensen 1954, Schoenike *et al.* 1962).

Some of these parental seed sources were selected specifically for good or poor form. Yet at age 10 all the sources were of poor form and the form of the trees bore little relation to the form of the parental seed source. Neither was the growth of the trees related to parental stand site or age.

In the winter of 1947-48 trees in seed sources from Lower Michigan showed severe winter injury, but their survival and subsequent growth was unaffected.

#### *The Lake States Jack Pine Seed Source Study*

In 1952 the University of Minnesota and the North Central (then Lake States) Forest Experiment Station

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<sup>1</sup> Canavera, David S. *Geographic variation in jack pine.* (Manuscript in preparation.)

<sup>2</sup> Data on file, USDA Forest Service, North Central Forest Experiment Station, Institute of Forest Genetics, Rhinelander, Wisconsin.

started a cooperative study of variation in Lake States seed sources of jack pine. Seedlings grown from seed collected in 29 natural stands in Minnesota, Wisconsin, and Michigan were used to establish 17 permanent test plantings in the three States (Rudolf and Jensen 1955, Jensen *et al.* 1960, Arend *et al.* 1961).

After 10 years in the field, trees from the Lower Michigan seed sources were the fastest growing in plantings throughout Michigan and most of Wisconsin (King 1966). Even in the Minnesota plantings located south of Duluth, two of the five tallest seed sources were from Lower Michigan (Alm *et al.* 1966, Alm and Jensen 1969). But in the Minnesota plantings located from Duluth northward, and in some of the colder sites of Wisconsin, trees from north-central Minnesota seed sources grew faster than those from the Lower Michigan seed sources. The best source in each planting averaged from 7 to 17 percent above the mean for all the sources.

Form and stem curvature were also evaluated in this study.<sup>3</sup> Occasional differences between seed sources were found but these differences were not consistent between sites. Differences in stem curvature were much greater between plantation locations than between seed sources within a plantation.

As in the other jack pine seed source studies, survival is excellent. When seed source differences in survival were found, even the sources with the lowest survival produced enough seedlings to form a well-stocked stand.

Seed source differences in insect and disease incidence were also found in this study (King 1971), but there were indications that sources resistant to one pest may be highly susceptible to others. Until more is known about the interrelationships between various jack pine pests, it may be best not to select intensively for pest resistance.

## Individual Tree Variation

### Michigan

In 1965 and 1966 seed was collected from 382 single trees in 61 natural jack pine stands in the Lower

Peninsula of Michigan. Trees were selected for open cones and above- and below-average height grown and stem straightness. The seedlings were grown at the Tree Research Center, Michigan State University, and used to establish six test plantations in Lower Michigan.

Based on 2- and 3-year nursery data, Canavera<sup>4</sup> concluded that parental selection for growth rate was ineffective; i.e., using his method of selection, there was no correlation between parental growth and progeny growth. Good parents could, on the basis of progeny testing, be chosen from stands that are phenotypically good or poor. The fastest growing progeny ranged from 17 percent above the mean in 2-year height to 28 percent above the mean in 3-year height.

Canavera found a north-south trend in the Lower Michigan trees and recommended that in a selection program for an area the size of Lower Michigan, parents should be chosen from the southern half of the area.

There were seedlot differences in the number of trees with lammas growth, but these differences could be ignored because lammas growth was not correlated with either growth rate or winter hardiness. Selection for early flowering also appears unnecessary as all families flowered early.

### Minnesota

In the spring of 1971 material for an individual-tree study was nursery-sown in the Northwest Paper Company nursery near Cloquet, Minnesota. About 320 seed collections made from individual jack pine in Minnesota are involved. No results have been reported as yet.

## CONCLUSIONS FROM PAST RESEARCH

### Growth Rate

Substantial improvement in growth rate is possible in jack pine. This improvement may arise from: (1) selection of superior seed sources and (2) selection of superior parents within the superior seed sources.

<sup>3</sup> Data on file, USDA Forest Service, North Central Forest Experiment Station, Institute of Forest Genetics, Rhinelander, Wisconsin.

<sup>4</sup> Canavera, David S. Variation among jack pine (*Pinus banksiana* Lamb.) half-sib families from 61 stands in Lower Michigan. (Manuscript in preparation for publication.)

Depending on the planting area in question, and on the quality of seed presently being used, we can expect growth rate increases of 7 to 15 percent with the choice of better seed sources. The data from the Lower Michigan study suggest that we can get an additional increase of the same magnitude by progeny testing and selecting the best parents within the superior stands. Thus, we can expect to find jack pine seedlings whose growth rate exceeds the present average-run jack pine by about 10 to 25 percent.

It must be emphasized that locating such superior parents will require a well-planned progeny testing program. The phenotypic growth rate of the parents is no indicator of the growth rate of the progeny.

## Survival

It now seems clear that planting failures with jack pine are the result of either poor planting practice or poor site selection. Given reasonable care, all Lake States seed sources provided satisfactory survival on Lake States planting sites.

*The penalty for selecting the wrong seed source is a reduction of increment and not of stocking.*

## PROPOSED IMPROVEMENT PROGRAMS

### Short-Term Program

I suggest we could combine the principle of seed production areas (SPA's) with the results of our provenance tests to produce improved seed for the Lake States quickly and cheaply.

Seed-production areas are natural stands that have been thinned to favor increased seed production. The chief advantage of SPA's is the small initial investment, and the short time interval before seed harvesting. Their chief disadvantage (particularly with a species such as jack pine) is the unknown genetic quality of the seed because SPA's are not usually progeny tested.

To offset this disadvantage, I propose that we consider our presently existing seed source studies to be (stand) progeny tests. We would choose the best parent stands on the basis of our seed source studies, relocate these parent stands, and convert the parent stands into seed-production areas.

Commercial quantities of seed would be available within 5 years, and the seed would be superior to the present run-of-the-mill seed because it would be from tested parent stands. We could expect a 5 to 15 percent genetic gain due to seed source selection, but none due to individual tree selection within stands.

Listed below are some of the seed sources that might be developed into seed-production areas in Minnesota, Wisconsin, and Michigan:

<i>Planting area</i>	<i>Recommended seed source<sup>5</sup></i>
Minnesota, east of a line from Duluth to International Falls	1592 Lake County, Minn. 1602 Itasca County, Minn.
Minnesota, west of a line from Duluth to International Falls	1595 Pine County, Minn. 1596 Pine County, Minn.
Minnesota, south of Duluth	1610 Oneida County, Wis.
Wisconsin and Michigan	1616 Manistee County, Mich. 1618 Alpena County, Mich.

To initiate this program we would partially remeasure several of the established test plantings of our Lake States Jack Pine Seed Source Study. Only trees from the five or six tallest sources would be remeasured in each planting to confirm the superiority of the selected seed sources. The parental stands would then be relocated and thinned to about 60 trees per acre to become a seed-production area. Although individual phenotypic tree selection is of little value in jack pine, the thinning should be on the basis of spacing, growth rate, and form.

Remeasurement and relocation of the parent stands would take less than four man-months. In all, we could probably develop six 5-acre seed-production areas<sup>6</sup> for less than \$7,000. There would, of course, be additional annual costs in seed collection and SPA maintenance, but all these costs would be only a small fraction of the value of even a minimal 5 percent increase in jack pine yield.

### Long-Term Program

In the long run, the greatest genetic improvement in jack pine will come from a program based on continued cycles of progeny testing, selections, and interbreeding the selected parents. A practical way of starting such a program lies in the development of seedling seed orchards.

<sup>5</sup> For exact legal description of parent stand location, see Rudolf and Jensen (1955).

<sup>6</sup> A 5-acre jack pine area containing about 210 trees would produce enough seed to furnish 1 million plantable seedlings per year (Rudolf 1959).

Seedling seed orchards are essentially progeny tests in which the progeny are used as seed parents. Thus, the initial investment in progeny testing is offset by the practical benefit of obtaining improved seed from the seed orchard. This approach also yields the type of information needed to plan additional cycles of genetic selection.

This proposed long-term program is almost identical to the program started in Lower Michigan and in Minnesota (see previous section on individual tree variation). It would begin with the selection of areas where better seed sources might be found (according to the results of our provenance tests) for a particular planting region.

Between 300 and 400 trees overall would be chosen from within several stands with no more than 15 individuals per stand. Open-pollinated seed would be collected from each of the 300 to 400 trees.

Keeping the seedlots separate by individuals, the seed would be sown in a replicated arrangement and insofar as possible in a nursery that is located near the center of the planting area. (This should minimize the seedlot x environment interaction in future field planting programs and thus make the nursery measurements more reliable indicators of mature tree performance within the planting region.)

On the basis of 2 years' nursery growth, only trees from the 200 fastest growing seedlots would be used to establish two or three test plantations over the planting area.

The progeny test plantings will be converted to seed orchards when the trees begin to bear regular pollen and cone crops. This should be about 7 or 8 years after field planting. The plantings would be measured at that time. On the basis of these measurements, the plantings will be thinned (1) by removing all the individuals in the below-average seedlots and (2) by removing some of the poorer individuals in the above-average seedlots.

Removing all seedlings from the poorest seedlots (half-sib family selection) would give the greatest gain in the genetic quality of the seed from these orchards. Removing individuals within superior seedlots might also yield some gain, but the primary consideration when thinning within seedlots should be spacing of the remaining trees.

About half of the seedlots would be removed at the first measurement and thinning. At age 12 to 14, the planting would be remeasured and thinned to leave one tree in four of the best 25 seedlots (about 40 to 50 trees per acre). Such heavy culling would not only improve the quality of the seed, but would promote heavy crown development and improve seed production among the parent trees.

To develop the next cycle of seed orchards we would artificially hybridize the remaining parents in as many combinations as possible. The identity of each tree x tree combination would be maintained separately and these two-parent families used to establish more seedling seed orchards. Such full-sib orchards should give almost twice the genetic improvement of the open-pollinated orchards and would eventually replace them.

Over the first few cycles of breeding we can probably expect to increase the growth rate of jack pine by 5 to 8 percent per generation.

This long-term seedling seed orchard program would, of course, require a much greater investment than the short-term seed-production area program. Because of the large number of variables involved it is difficult to evaluate the profitability of the long-term program. For instance, Lundgren and King (1965) found that in evaluating financial returns from a hypothetical jack pine improvement program, planting site quality was an important variable. Planting genetically superior stock pays off more on high quality sites than on low quality sites. Annual planting acreage is also very important.

Without going into detailed calculations, it would seem on the basis of Lundgren and King's (1965) data that the first cycle of the seedling seed orchard program proposed here would offer a 7 to 9 percent return on the initial investment.

It would therefore seem that tree improvement programs in jack pine are a low-cost method of increasing future pulpwood supply.

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# THE WESTERN GULF FOREST TREE IMPROVEMENT PROGRAM, HISTORY AND ORGANIZATION

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The following remarks are primarily an account of the experience of the Texas Forest Service in organizing the Western Gulf Forest Tree Improvement Program (WGFTIP) and the philosophy that went into its development. The program of the Texas Forest Service has had two very distinct phases, although in both phases it was a cooperative effort. The initial phase lasted from the organization of the program in 1951 until the middle 1960's. Initially the program was supported by a combination of State and industrial funds, with the State of Texas providing the lion's share of the cost, but with several industries giving additional financial support. At this time the program was mostly research-oriented. Practical experience in tree improvement was largely lacking and most of the effort went into developing techniques for selection, grafting, seed orchard management, and progeny testing. The results were generally available and advice was given to other organizations, but the basic philosophy of the program at that time was one of research rather than service.

The second phase of the program became effective in 1969, with the organization of the Western Gulf Tree Improvement Program. The outlook of this organization is considerably different and I will spend the remainder of my talk on this and similar tree improvement programs.

## OBJECTIVES OF THE WESTERN GULF FOREST TREE IMPROVEMENT PROGRAM

Looking at such different organizations as the Western Institute of Forest Genetics, the Lake City Genetics Project, the North Carolina State Cooperative Program, and the Spruce-Fir Program in New

England, it is clear that the objectives of a tree improvement program can vary greatly. At this point I would therefore like to be specific and quote you the objectives of WGFTIP as adopted at its organizational meeting.

"The objective of the Western Gulf Forest Tree Improvement Program is to provide sustained and co-ordinated leadership and technical assistance in the selection, propagation and genetic testing of desirable clonal lines of southern pine and hardwood species. Further objectives are to promote cooperation in the area of forest genetics through the exchange of information, data, assistance and plant materials between and among members, as well as the promotion of pertinent research."

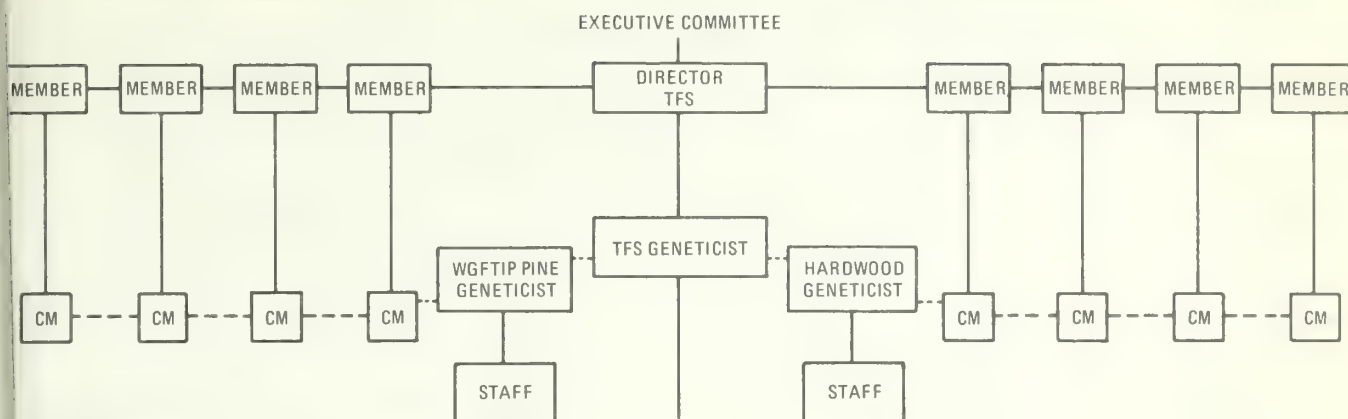
There are two key phrases in this lofty prose: (1) technical assistance and (2) cooperation through the exchange of information and plant materials among members. These two ideas — technical assistance and cooperation — are the essence of a cooperative program, although indeed a great number of other ingredients are necessary to make one operate smoothly.

## MEMBERSHIP

Membership of the WGFTIP organization is open to all interested organizations within its geographic area. The organization started with 13 charter members, including two State organizations, three organizations with primary interest in lumber and/or plywood, and eight organizations with primary interest in pulpwood. Since then two additional State organizations and three industries have joined the program, making the total membership 18. The above grouping is some-

## PINE PROGRAM

## HARDWOOD PROGRAM



CM = CONTACT MEN

Figure 1. – Organization chart of the Western Gulf Forest Tree Improvement Program.

what arbitrary, because the larger organizations especially are interested in a wide spectrum of forest products. Although there are not strict requirements for membership, it is felt that to justify its own seed orchard program an organization should be managing a minimum of 200,000 acres of forest land.

## ORGANIZATION

Most of the cooperative tree improvement programs are rather similar in organization, although names and titles may differ. The WGFTIP is governed by an executive committee consisting of one representative of each of the member organizations (fig. 1). The representative on this committee is one of the higher executives, capable of making policy decisions for the organization he is representing. In addition, each member organization appoints a contact man, who is responsible for the day-to-day operation of the company's tree improvement program. All arrangements for fieldwork, such as tree grading, grafting, progeny testing, and cone collection, are made through him. There are two scheduled meetings per year, one for the executive committee and one for the contact men.

Initially the program was limited to the genetic improvement of pine, but starting January 1971 a hardwood program was added. It is organized as a hardwood committee consisting of the WGFTIP members interested in hardwood improvement. Currently the hardwood committee has seven members.

## SERVICES PROVIDED

Generally speaking technical assistance to the members is limited to those aspects of tree improvement work that the members are not well equipped to handle themselves. Following is a quote from the WGFTIP organizational meeting:

"The services and assistance provided members of the program will include, but not be confined to, the following:

- (a) Establishment of criteria for selecting superior trees.
- (b) Final grading of superior trees.
- (c) Training in grafting.
- (d) Selection of nursery and orchard site.
- (e) Assistance in orchard design and management.
- (f) Design of progeny tests.
- (g) Data analysis.
- (h) Record keeping and data retrieval on clone performance.
- (i) Availability of clonal material of proven genetic quality developed by Texas Forest Service.
- (j) Arrangement for exchange of plant material between members."

The activities in effect have varied a great deal from member to member. It seems that especially in

the early phases of the program most time is spent on training and on superior tree selection. Training has taken various forms. So far we have taught two short courses. These are designed to give a general background in forest genetics to people who have never been exposed to it before. This is followed up by smaller training sessions, usually held for one or two companies at a time, in a specified area of work. John Robinson, for instance, has conducted a number of sessions in grafting. As time goes on we can expect that the emphasis will shift considerably to seed orchard management and progeny testing. At the moment data analysis has not been a major activity, but this again will be one service many of the members will take advantage of once progeny test results become available.

### **FACTORS NEEDED TO MAKE A COOPERATIVE PROGRAM SUCCESSFUL**

There are a number of factors that contribute to the success of a cooperative tree improvement program. First of all, the time has to be right for it. This means that in the region under consideration there should be an intensive planting program underway or it should be clear that such a program will be started in the very near future. There should be some aggressive industry or state organizations, who are 100 percent behind the idea and are willing to engender a similar interest in other organizations in the area. And lastly there should be enough potential financial support to carry such a program.

Once the program is underway there are two other

factors that can make or break a program:

1. There should be a clear understanding, that it is the program of the cooperators. It is done 100 percent for them and most of the work is done by them. The work done by the professional staff employed by the cooperative is only the top of the iceberg. The bulk of the work will have to be done at the grass roots level by the individual members. This should work both ways. In other words, since the members are doing most of the work, they are also the ones that deserve the credit for what is accomplished. It is important that this is made clear whenever possible.

2. There should be a truly cooperative spirit among the members. Only through willingly shared experiences and exchange of selected materials and proper techniques quite often learned the hard way can a program advance. If any of the members become proprietary about techniques and improved clones a cooperative program will lose its viability.

### **CONCLUSIONS**

These are some of our experiences and our philosophy on cooperative tree improvement. The road that has been taken in the South has certainly been highly successful, but it doesn't mean that it is the only way to do it, nor that it might even be appropriate under different circumstances. I do believe, however, that no matter what the circumstances are, a cooperative program cannot succeed unless it is built around a program of service to its members and intensive participation by its members, and unless there is a truly cooperative spirit among the participants.

# THE NEW ENGLAND SPRUCE-FIR SEED ORCHARD PROGRAM

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I once heard it said that if you want to know how something was organized, ask a man who had nothing to do with it. I suspect this may be one of the reasons I was asked to collaborate on this report of the development of the New England Spruce-Fir Seed Orchard Program.

What I would like to do today is give you a brief history of our program and then present a few of the problems we encountered — how we might have avoided them and what we have done to solve them. And then, with the excuse of author's prerogative, I'd like to make observations on the organization of tree improvement programs, based on our rather limited experience.

The spruce-fir program began in 1965 when Arthur Hart, USDA Forest Service Project Leader at Orono, contacted forestry leaders in northern New England and New York and suggested a meeting to discuss the feasibility of initiating a tree improvement program for spruce-fir. Several meetings were held, and a Steering Committee was formed, including one representative each from industry, State forestry, State university, USDA Forest Service State and Private Forestry, and two representatives from USDA Forest Service Research.

The stated objective of the program, covering an initial period of 3 to 5 years, was to begin identification, detailed location, and seed collection of "plus" or superior individual trees of the spruce-fir type.

Seed collected from these individuals was to provide, through the development of seedling seed orchards, a better seed source to fulfill future planting requirements. In general, the functions of the program were divided as follows:

1. The USDA Forest Service was to provide technical knowledge and leadership and commensurate manpower to provide direction and to make the necessary computations.
2. The State Forest Services were to cooperate in general field work relating to "plus" trees — seed collections, nursery work, and outplantings.
3. Industry was to cooperate in supplying manpower for the necessary fieldwork relating to "plus" tree selection, seed collections, and outplanting, and to make available the necessary equipment and machine time. It was to provide desirable planting sites within its ownership areas.

Species requirements were rather vague, and they varied from merely spruce and fir to a variety of species. Early preference pointed to the following order: balsam fir, white spruce, Norway spruce, and white pine. Red spruce was considered, but not included because of a general agreement on lack of genetic variability in the species. Later, the number of species was reduced, and we now concentrate on balsam fir and white spruce. Some black spruce have been selected but the species is not well distributed throughout the region.

In choosing "plus" trees, factors were selected to favor growth rate first, then the highest possible combination of growth rate and wood density, and then height to diameter ratio. Favor was not shown towards tree form or angle of branching. The selection criteria reflected the needs of the pulpwood industry in the area and the historic and planned utilization of the species. Even so, the criteria were not biased against the potential use of the superior stock for saw-log production.

Although the major emphasis of the program was on seedling seed orchards, scions were collected from the "plus" tree candidates to preserve their germ plasm against potential losses from cutting, wind-throw, insects, and disease. Also, preservation of the selected clones would permit, at some future time, the development of small clonal orchards and a breeding arboretum.

Training sessions were held throughout the spruce-fir region to train foresters in the uniform reporting of "plus" tree candidates. Attendance at these sessions was excellent, and the selection of "plus" trees began in 1966. By June 1970, 80 balsam fir, 55 white spruce, and three black spruce had been selected and subsequently screened for acceptance by the USDA Forest Service State and Private Forestry geneticist assigned to the program.

Most of the selections were made in 1966 and 1967, but the lack of good seed crops and a break in leadership due to the death of Arthur Hart stalled the program. However, pressure from industry and the potential of a good seed year led to a reorganization of the program in June 1970. A new Steering Committee was appointed, and plans for seed collections and nursery plantings were made and finalized.

Nearly all the "plus" trees were revisited. In all, 58 seed lots were collected by the owners and moved to the Maine State Nursery by the Maine Forestry Department. Seed cleaning and nursery sowing were supervised by a forester and a geneticist of the State and Private Forestry Division of the USDA Forest Service. One replication of each seed lot was planted in the Maine Nursery in the fall, and another was planted in the spring. One replicate was planted in the fall at the New Hampshire State Nursery.

Now that we have seedlings in the nursery, we are preparing to meet the problems of outplanting and care of the plantations. We plan to have plantings on

forest sites provided by industry, universities, and Federal and State forestry agencies. We are asking all the cooperators to begin site preparation at least 1 year before the stock is ready to be planted. Our Forest Service Research Project at Orono is also starting a research program to develop the intensive cultural practices that are essential to realize the full potential of superior stock.

We are also requesting landowners to make additional "plus" tree selections. We have settled on 150 trees of each species as the minimum number needed. In any good seed year, this should give us a sufficient number of seed lots for comparison purposes.

We feel that we have made progress, but we realize that our program is still in its infancy. We have had many problems and anticipate many more. Because our objective here is to discuss problems and solutions in the organization of a tree improvement program, I will cover some of the pluses and minuses of our experiences during the last 6 years.

On the positive side, from the beginning, industry has shown an active interest in the program. This is undoubtedly related to the fact that economic benefits have been realized from tree improvement programs in other sections of the country, particularly in the South. However, it is also related to the fact that foresters in the executive branch of industry in Maine recognize the need to begin now if we are to have superior trees to produce the greater yields per acre necessary to offset the reduction of our productive forest land base through diversion to other uses such as recreation, highways, and homesites. The rising costs of wood transportation and land taxes indicate a need for concentrating growth as close to the market and on as few acres as possible.

In general, the attitude of industry is typified by a comment made by Jim Carlaw of International Paper at the first meeting of the Spruce-Fir Committee in 1965. I quote: "Current economics do not favor planting or direct seeding on a substantial scale, yet I am convinced that in the future economics will favor artificial regeneration with improved seeds or planting stock. At that indefinite time we will wish we had started sooner on genetic improvement."

Another plus is that the program has been completely cooperative and as such has not required a big labor commitment or large out-of-pocket expenditures by any one group or organization.

But we have had minuses — problems — some of our own making, some the result of the vagaries of nature. Briefly they are:

*Too few trees.* — Assuming that our program has been active for 5 years, we should have more than our maximum of 80 trees of a single species. Those who have lived with the program feel that we may have given the impression that foresters making the selections should seek the one very best tree on their entire holdings rather than the best tree in a particular area. We are now requesting that any tree that appears “plus” or exceptional when compared to the high average of the stand be reported. Fieldmen thoroughly experienced with the forest type and species can easily make these comparisons.

*Not enough communication.* — We have not always kept the people involved in the program up-to-date on past progress and future needs. A newsletter was planned and started, but was not kept up on a regular basis. Personnel in all organizations changed and because there was no communication with their replacements, continuity and program impetus were lost. We now issue a letter to all members of the program whenever there is any news such as results of seed collection, nursery planting, new trees submitted for screening, or when, as now, we feel the need to stimulate the search for more “plus” trees.

*Lack of central record keeping with rapid retrieval.* — Closely allied with our communication problem has been our inability to retrieve information quickly on the accepted “plus” trees. People who go to the trouble of selecting and submitting candidates like to know what happens to them, how their company compares with others in the number of candidates submitted, and what the status of the program is in terms of total candidates. We now are developing a computer program to store the information and make simple calculations on characteristics of “plus” tree candidates. We will get printouts from this program for periodic distribution to all the cooperators.

*Seed years.* — Nature dealt our program an almost mortal blow by denying us a good seed year early in the program. Selection of candidates went very well, but the program was nearly dormant during the off seed years. Obviously there is nothing we could do about this, but we feel that this fact should be recognized in organizing a tree improvement program for a species that does not produce seed crops frequently. Some seed was collected, but in only one case was

there a sufficient quantity to warrant seeding in the nursery. Seeds from three trees — one balsam fir, one white spruce, and one black spruce — were collected, planted in 1967, lifted in 1971, and outplanted on the Forest Service Penobscot Experimental Forest and land of St. Croix Paper, the company that collected the seed.

*Failure to preserve the germ plasm.* — Our scion wood collection has not been actively pursued, and some candidates have been lost because of it. The trees lost either died, were windthrown, or were inadvertently cut during logging operations. We have had very little success with grafting the few scions that were collected. Not only is the grafting of spruce and fir difficult, but many of our “plus” trees are nearly inaccessible during the winter months when scion collections should be made. We have not yet hit upon the solution to this problem.

*Leadership.* — Leadership is a problem because in a cooperative program involving several public agencies and industry, someone — and I stress the one — must assume the responsibility for pushing the program. This is particularly true when the program represents a small but recurring effort on the part of the participants. Arthur Hart of the USDA Forest Service was dedicated to the program and provided the annual drive necessary to keep it going in the early years. My co-author, Jim Carlaw, has now assumed the role, enabling the program to continue. But had Jim, or someone like him, not been prepared and willing to assume the responsibility for the program, it might have been lost.

From discussions with those who were involved in the organization of the Spruce-Fir Program and a review of the past 6 years' correspondence, we feel that there are several “musts” in the development of a tree improvement program. We realize that these needs are not new, but we feel that they are fundamental and bear repeating in the context of our discussions here.

There must be an individual or group of individuals of significant professional influence, who are sold on the genetic improvement of the species in question. To illustrate, I will again quote from Jim Carlaw's comments at the first meeting in 1965:

“I think we need to start now formalizing a program to identify our needs to locate trees — “plus” trees that meet our needs. We ought to start genetic

improvement programs. I would suggest that it might be difficult to sell this to industrial management on the basis of an immediate need — I think decisions ought to be based on economic appraisals made on the basis of alternatives available today.” When the Woodlands Manager of a large corporation talks this way, tree improvement has a real chance for success.

The people who set up and provide the initial impetus to the program must have the authority in their own organizations to commit people and money to the effort. In our case, these people included woodland managers, State foresters, forestry school directors, Forest Service assistant directors in Research and State and Private Forestry, and National Forest supervisors.

Initially the effort must be both modest and cooperative. No public or private agency can be expected to embark alone on a full-scale tree improvement program until some economic or environmental benefits are on the horizon.

The initial leadership must come from some public agency such as the State or Federal Forest Service

or a forestry school. These agencies generally have the expertise at hand to provide the necessary technical assistance without adding personnel or committing large sums of money to the project. Also, at least in our area, much of the land that will ultimately be regenerated by genetically improved seed is now owned by the general public; and this is a sound basis for the government — State and Federal — to participate.

Finally, after it is organized, tree improvement is an action program and should be treated as such. Meetings to plan the necessary field actions should not be cluttered with discussions on the various genetic alternatives involved. For example, once you have embarked on a seedling seed orchard program, meetings to organize seed collections are not improved by discussions of the relative merits of seedling versus clonal orchards. Industrial cooperators and others as well are confused and disillusioned by such arguments. To gain and maintain interest in a tree improvement program, those people with expertise in the genetics of the species involved must agree, in public at least, on the immediate needs and the future potential benefits of the planned course of action.

## COMMON AND SCIENTIFIC NAMES OF WOODY SPECIES MENTIONED IN THE TEXT

Ash, white	<i>Franxinus americana</i> L.
Aspen, bigtooth	<i>Populus grandidentata</i> Michx.
Aspen, quaking (trembling)	<i>Populus tremuloides</i> Michx.
Birch, yellow	<i>Betula alleghaniensis</i> Britton
Cottonwood, black	<i>Populus trichocarpa</i> Torr. & Gray
Cottonwood, eastern	<i>Populus deltoides</i> Bartr.
Dawn redwood	<i>Metasequoia glyptostroboides</i> Chen & Hu
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco
Fir, balsam	<i>Abies balsamea</i> (L.) Mill.
Fir, Fraser	<i>Abies fraseri</i> (Pursh) Poir.
Fir, white	<i>Abies concolor</i> (Gord. & Glend.) Lindl.
Hemlock, eastern	<i>Tsuga canadensis</i> (L.) Carr.
Larch, eastern	<i>Larix laricina</i> (Du Roi) K. Koch
Larch, Japanese	<i>Larix leptolepis</i> (Sieb & Zucc.) Gord.
Maple, sugar	<i>Acer saccharum</i> Marsh.
Oak, northern red	<i>Quercus rubra</i> L.
Pine, Austrian	<i>Pinus nigra</i> Arnold
Pine, eastern white	<i>Pinus strobus</i> L.
Pine, jack	<i>Pinus banksiana</i> Lamb.
Pine, Japanese red	<i>Pinus densiflora</i> Sieb & Succ.
Pine, red	<i>Pinus resinosa</i> Ait.
Pine, Scotch	<i>Pinus sylvestris</i> L.
Pine, southwestern white	<i>Pinus strobiformis</i> Engelm.
Poplar, balsam	<i>Populus balsamifera</i> L.
Poplar, black	<i>Populus nigra</i> L.
Poplar, gray	<i>Populus x canescens</i> (Ait.) Sm.
Poplar, white	<i>Populus alba</i> L.
Spruce, black	<i>Picea mariana</i> (Mill.) B.S.P.
Spruce, Norway	<i>Picea abies</i> (L.) Karst.
Spruce, red	<i>Picea rubens</i> Sarg.
Spruce, Serbian	<i>Picea omorika</i> (Pancic) Purky
Spruce, white	<i>Picea glauca</i> (Moench) Voss
Sycamore, American	<i>Platanus occidentalis</i> L.
Sweetgum	<i>Liquidambar styraciflua</i> L.
Yellow-poplar	<i>Liriodendron tulipifera</i> L.
White-cedar, northern	<i>Thuja occidentalis</i> L.

**ATTENDANCE**  
**TREE IMPROVEMENT CONFERENCE**  
**Madison, Wisconsin**  
**September 22-24, 1971**

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**Publications of Proceedings  
of the  
Lake States Forest Tree Improvement Conference**

- First, Mar. 30 - Apr. 1, 1953. Lake States For. Exp. Stn. Misc. Rep. 22, 83 p. 1953.
- Second, Aug. 30-31, 1955. Lake States For. Exp. Stn. Misc. Rep. 40, 108 p., illus. 1955.
- Third, Sept. 17-18, 1957. Lake States For. Exp. Stn., Stn. Pap. 58, 87 p., illus. 1958.
- Fourth, Oct. 6-7, 1959. Lake States For. Exp. Stn., Stn. Pap. 81, 60 p., illus. 1960.
- Fifth, Sept. 19-20, 1961. Lake States For. Exp. Stn., Stn. Pap. 98, 42 p., illus. 1962.
- Sixth, Sept. 9-10, 1963. Lake States For. Exp. Stn. (no series), 90 p. 1964.
- Seventh, Oct. 21-23, 1965. USDA For. Serv. Res. Pap. NC-6, 110 p., illus. 1966.
- Eighth, Sept. 12-13, 1967. USDA For. Serv. Res. Pap. NC-23, 60 p., illus. 1968.
- Ninth, Aug. 22-23, 1969. USDA For. Serv. Res. Pap. NC-47, 34 p., illus. 1970.

## ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:



- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

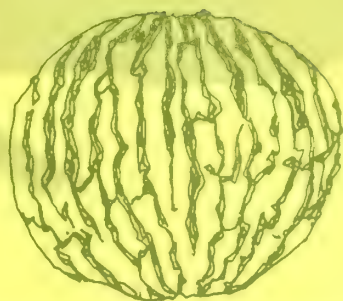
The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.

# BLACK WALNUT

as a crop



Black Walnut Symposium—Sponsored by:

Carbondale, Illinois—August 14-15, 1973

Walnut Council—Southern Illinois University—USDA, Forest Service

North Central Forest Experiment Station • Forest Service  
U.S. Department of Agriculture

# FOREWORD

The North Central Forest Experiment Station and the Northeastern Area, State & Private Forestry of the Forest Service appreciate the opportunity to join with Southern Illinois University and the Walnut Council in sponsoring this second symposium on the culture and use of black walnut. Active participants include members of the walnut industry and private landowners as well as scientists and specialists from various universities and State and Federal agencies. What these resourceful people have accomplished in a relatively short time says it all — cooperation pays off.

Southern Illinois University's contribution to walnut research and extension goes far beyond hosting the 1966 and 1973 Symposia. Through its School of Agriculture and Department of Forestry, the University has taken an active part in developing our cooperative research program by contributing space, funds, and scientific expertise. We know these contributions will pay big dividends for many years to come.

One of the primary objectives of the Walnut Council is to extend knowledge on how to tend and utilize black walnut trees. Its co-sponsorship of the symposium and its financial assistance in the publication of the proceedings are proof of the Council's interest and enthusiasm.

The papers in these proceedings clearly demonstrate that the state of the art and science of walnut culture has advanced considerably since the first Walnut Symposium in 1966, but they also indicate that a number of serious or potentially serious problems remain to be solved. Obviously, we can do more to increase the growing stock, to speed up growth, and to improve quality and utilization. We must not let up in our effort to learn more about walnut culture and to apply what we learn.

JOHN H. OHMAN, *Director*

North Central Forest Experiment Station

ROBERT D. RAISCH, *Director*

Northeastern Area, State & Private Forestry

**North Central Forest Experiment Station  
John H. Ohman, Director  
Forest Service, U.S. Department of Agriculture  
Folwell Avenue  
St. Paul, Minnesota 55101**

(Maintained in cooperation with the University of Minnesota)

# **BLACK WALNUT AS A CROP, Black Walnut Symposium, Carbondale, Illinois, August 14-15, 1973**

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# PROGRESS THROUGH COOPERATION

**John R. McGuire, *Chief***  
*USDA Forest Service*  
*Washington, D.C.*

I welcome the opportunity to meet with you on this beautiful campus. We share a deep interest in finding better ways to grow and utilize black walnut and other fine hardwoods.

Seven years ago, at the first Black Walnut Workshop, former Chief Ed Cliff, Dr. Delyte Morris, then president of Southern Illinois University, leaders in the fine hardwoods industry, and several hundred staunch supporters of black walnut dedicated the Tree Improvement Center here at Carbondale. Those of you who were present will recall that the area consisted of 40 acres of School of Agriculture pastureland and a few dozen newly planted walnut trees. Now the area contains excellent facilities for tree improvement research, all developed through the direct assistance of Southern Illinois University.

I would like to stress that the Tree Improvement Center and our new Forestry Sciences Laboratory were made possible through the support and cooperation of a great number of people. In fact, the walnut research and development program would not exist at all if it were not for a strong cooperative spirit. Various State, Federal, private organizations, and universities are working with hundreds of private landowners who have freely given of their land, their trees, and their time. This cooperative effort was further strengthened in 1970 with formation of the Walnut Council.

My sincerest congratulations to all of you for showing how effectively a grass roots movement can identify and vigorously pursue solutions to problems in resource management, especially as they apply to private lands. We in the Forest Service are proud to be a part of this program.

As many of you know, the Forest Service recently completed another review of our timber resources. The total hardwood situation has changed little from that shown in the 1962 Timber Trends Study. The 1970 volume growth exceeded drain, but high-quality logs are in short supply and the long-range outlook is not bright. Most of you know better than I that the prospect for quality walnut is bleak. In view of the intense pressure on the walnut resource during the past 10 to 15 years, I was amazed to see how much walnut growing stock still is present. This is evidence of the high value landowners place on both young and old walnut trees.

We are well aware that short supplies of veneer and saw logs are a critical problem for industry. Continuing strong export demands have further depleted the available supply and created difficult times for our domestic primary processors. Some of them have not survived the "crunch." Although the grower has benefited from the constantly rising prices for his trees, this trend is not without hazard. Walnut can more than hold its own on technical merits in competition with other woods and substitutes, but there are limits to what people will pay for genuine walnut products. If this beautiful

wood is to retain its traditional place in a highly competitive market, it is obvious that we must find more efficient ways to grow and process walnut.

Considerable progress has been made toward finding solutions to some urgent problems. I am impressed that a lot of good research is being carried on at a number of locations. The papers presented during this symposium provide excellent summaries of what is now known about growing, harvesting, and utilizing black walnut for wood products and nuts. We should not fail to stress another desirable attribute of walnut trees, their esthetic value. Walnuts, especially open-grown trees, are an important part of the scenic beauty of the central hardwood region, both in summer and winter.

During the last Walnut Workshop, various speakers suggested that improvements in survival, growth, and quality were possible if certain practices were followed. In this meeting, you will learn that many of these early predictions were correct.

Perhaps the greatest progress in the past 7 years has been made in the field of extension. Research results are now made available promptly, so little time is lost in getting improved techniques into practices. This has been a team effort, and you should be proud of the results.

Communication between research and extension personnel has been excellent. I'm sure that this is partly because the Forest Service staff at Carbondale includes a well-qualified specialist from our Division of State and Private Forestry. This has resulted in close liaison with the State Divisions of Forestry and State and industry extension staffs. High landowner interest in obtaining planting stock and participating in cost-sharing programs shows that the linkage between extension and the walnut growers is bearing fruit.

Last spring I received a copy of the February issue of *Plywood and Panel* from the publisher, Mr. James Burrell. The cover picture and the story about Bob Hollowell's walnut plantings near Martinsville, Indiana, show what can be done by a private landowner. The story describes a very successful large walnut plantation that is used by both research and extension to test and demonstrate management practices. Natural walnut trees on the same farm receive necessary release and pruning. Other companies and individuals are making similar intensive efforts to establish and grow walnut following the best advice they can get. You have a good story, and you need to tell it again and again.

We are making good progress, but we have a long way to go in solving all the urgent problems in walnut culture and use. For example, we know that intensive culture of any crop can create conditions favorable to insect and disease attacks. Much needs to be learned about the pests involved, their potential impact on growth and value, and the control measures that will be effective. Without this information, the landowner might lose his investment in walnut plantations or become so discouraged that he would stop trying to grow walnuts. Future supplies for industry would suffer.

We also need reliable data to determine the economics of growing walnut for wood and nut crops on both good and poor sites. Some individual landowners are trying unique multicropping systems — producing crops of grass, hay, or small grains between the trees in their young walnut plantations. Suitable techniques will have to be developed that minimize potential animal damage to the trees. We need to capitalize on such opportunities to improve income on farm operations.

The success or failure of our program to increase production of walnut and other fine hardwoods will depend on the degree of participation by nonindustry private landowners who own 75 percent of the hardwood sawtimber. Their land includes most of the productive walnut sites and nearly all the walnut growing stock. We need to stimulate greater interest among the small private landowners in developing maximum productivity of their forest lands. A good research and extension program will help, but experience has shown that direct incentives also can be reached.

Past and present cooperative forestry programs, such as the Civilian Conservation Corps, Prairie States Forestry Project, Cooperative Forest Management, Soil Bank, and the Rural Environmental Assistance Program, have resulted in the establishment of more than 35 million acres of plantations. I'm sure much of this progress would not have been made without these programs.

We know that use of intensive practices such as thinning and pruning can greatly increase walnut growth and quality. We also know that once a landowner begins to follow such practices he is apt to develop a continuing interest and pride in keeping his woodland productive. These are good arguments for a program to encourage planting more walnut and other fine hardwoods and applying cultural practices when they are needed.

The Forest Service is developing a financial incentives program for small woodland owners to assist them in improving productivity of their forest land. We feel this approach is a viable one for promoting good management practices on small ownerships. The small nonindustrial owner needs both financial and technical help.

Record prices for walnut have led to some vexing situations. I would like to challenge the Walnut Council and all of you attending this symposium to do something about two urgent problems. First, we need to convince landowners that they should not sell walnut trees just because they have reached minimum merchantable size, because the volume being added to such trees will produce the greatest rate of return. Second, we need to allay the fears of landowners who may consider selling their trees prematurely — before they are stolen. The actual volume of stolen trees is relatively small, but the wide press coverage given "tree rustling" surely has a detrimental influence on the landowner's decision. Prospective tree planters or those with trees needing release, thinning, or pruning might well become so discouraged about potential theft that they would hesitate to invest in walnut culture.

Although many problems remain to be solved, you can all be proud of what has been accomplished in this cooperative program. I hope you will take advantage of the momentum you have generated in walnut and expand this interest to include other fine hardwoods on small private forest holdings. How well these lands are managed will largely determine the role of fine hardwoods in meeting future needs for timber and in making our Nation a more attractive place to live.

# SEVEN YEARS OF GROWTH

Gene W. Grey, *Assistant State Forester*  
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Manhattan, Kansas

**ABSTRACT.**—The 7 years since the Black Walnut Workshop have shown a continued decline in walnut log quality. The application of new research, tree improvement programs, and intensive culture give hope, however, that this downward curve may soon flatten. The walnut industry must also address itself to problems of marketing, economics, seedling production, and even social areas.

In August of 1966, a landmark walnut workshop was held here at Southern Illinois University. Jointly sponsored by the USDA Forest Service, the American Walnut Manufacturers Association, and Southern Illinois University, the workshop was born of a genuine concern to improve the quality of the black walnut resource. Edward Cliff,<sup>1</sup> then Chief of the Forest Service, clearly expressed this concern in his keynote speech: "Efforts to improve supplies of quality timber in America are long overdue. The over-all quality of our hardwood timber resources has been in a long decline as we harvested the best trees of the most desirable species and left the poorest to grow and reproduce. We have at last reversed the downward trend in volume — now that growth exceeds cut — but we have a long uphill fight to improve the quality of the timber we grow — especially in the hardwood species."

Now, we are gathered here again, 7 years later, to see how far up the hill we have come, and how far we have yet to go. The objective of this symposium is to summarize the state of the art concerning walnut, to present relevant new information, and to identify what else needs to be done. To set the stage, perhaps it would be well to briefly review some significant happenings since the 1966 workshop, to illustrate some of our successes, and to identify, alas, some of our shortcomings.

The 1966 workshop was certainly not the beginning of black walnut in the nation. It was, rather, perhaps a

logical development growing out of all that had gone before. It did, however, focus attention on the species as nothing before had ever done, and thus must be regarded as an important landmark.

The challenge from that workshop — to reverse the downward trend in quality — has not yet been met. The walnut veneer and furniture industry is utilizing materials today that are of generally lower quality than 7 years ago. I quote Donald Gott of the Fine Hardwoods American Walnut Association, who after receiving opinions from a cross section of their membership said: "I am sorry to report the situation universally is severe from the standpoint of declining quality, and a continuation of a downward curve is quite evident."

So we can only hope that the curve may soon begin to flatten. A look at some of the happenings in walnut during the past 7 years gives reason for this hope:

*The Building of a Solid, Relevant Research Base.*—In the early 1960's, the USDA Forest Service made a commitment to an intensive effort in walnut research. This commitment was manifested in the development of the walnut research center here at Carbondale, related work at the Forest Products Laboratory, and the underwriting of numerous projects at universities within the species range. There has also been a significant input from other public and private organizations. We have confirmed some of what we thought, we have exploded some myths, and we have made some new discoveries. Most importantly, however, we have armed our field foresters with an accurate body of knowledge.

*The Application of Research Findings.*—While this happening spreads itself over others that I will discuss

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<sup>1</sup> Edward P. Cliff. *The increasing challenge of decreasing quality*. In *Black walnut culture*, USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn., p. 1-3. 1966.

later, it is significant unto itself, as application is not always the result of research in forestry.

*The Initiation of Walnut Tree Improvement Programs.*—Three States have developed improved walnut seed-production areas and are collecting seed from them. Nine others have seed orchards not yet in significant production. Superior trees have been located and propagated across the species range. Materials are being exchanged and testing is underway.

*The Intensive Culture of Existing Walnut Trees.*—Perhaps no other species in the history of American forestry has been as intensively managed as walnut. In our native woodlands, we are concentrating more on single trees than on stands. If we have not developed a totally new silvicultural system, we have modified the traditional one nearly beyond recognition.

*The Creation of the Walnut Council.*—The Walnut Council was born on September 1, 1970. This birth was the result of the conception some 9 months earlier at a tree improvement meeting in Hannibal, Missouri. The details of this conception and birth are available upon request. The general objectives of the Council are to advance knowledge of the culture of walnut species, to encourage the planting of walnut, to encourage the management of naturally established walnut, and to perpetuate the utilization of all walnut products. The only qualification for membership is an interest in walnut. We now have over 562 members representing 27 States and three foreign countries.

If we are to be objective, however, we must recognize our problems as well as our successes. It is in the spirit of constructive criticism that I offer the following comments as to our problems and areas of disagreement:

*Marketing.*—We are the forest industry with maximum confusion in the market place. Universal or regional log-grade standards are not used, and log-value information is not readily available to the seller. This confusion manifests itself in the criticism by service foresters of the industry's log-purchasing system, and conversely, the criticism by the industry of foresters who give log-value estimates to landowners. We skirt the edges of this problem, and seem afraid to meet it head-on. But, I believe we must, and I will recommend this as a priority item for the appropriate committees of the Walnut Council.

*Economics.*—Our knowledge of black walnut economics is weak. Even weaker is our application of the

economic knowledge we do have. The increased emphasis on walnut management in recent years is predicated on little more than an assumption that walnut is valuable and always will remain so. Foresters are recommending and landowners are carrying out cultural practices with only a vague understanding of the economic consequences of their actions.

*Monoculture.*—We have been criticized for concentrating on walnut at the expense of other hardwoods. This question has been raised most often from the standpoint of priorities for research monies. Another question seems appropriate, too: Are we practicing discriminatory silviculture in the woods, and might we not pay a high price for this in the long run? I have no answer here, but I have seen excellent sycamore, hackberry, and other species cut or girdled to release walnut in my own State. If this is the case throughout the species range, perhaps there is valid cause for concern.

*Chemicals.*—The uncontrolled use of herbicides and other chemicals is a very real threat to the walnut resource. In my own State, at the western edge of the walnut range, aerial application of herbicides in the name of pasture improvement and range conservation is widespread. In some counties it is virtually impossible to find walnut trees undamaged by 2,4-D or 2,4,5-T. Because of the mass application of these herbicides, grapes are no longer grown commercially in Kansas and portions of other States. That this could happen to walnut, too, cannot be shrugged off as another unfounded forecast of doom.

*Seedling Production.*—Production and distribution of black walnut seedlings has fluctuated greatly since 1966. Williams and Phares<sup>2</sup> reported that the State nurseries distributed 1.7 million walnut seedlings in 1966. This dropped to 1.4 million in 1967, and since has climbed to 2.7 million in 1971. State nursery distribution of stratified nuts has shown a similar pattern:

Year	Seedlings	Stratified	
		Nuts	Total
1966	1,673,420	536,411	2,209,831
1967	1,372,605	486,195	1,858,800
1968	2,377,669	433,124	2,810,793
1969	2,266,284	494,593	2,760,877
1970	2,532,646	451,900	2,984,546
1971	2,701,647	875,524	3,577,171

<sup>2</sup> Robert D. Williams, and Robert E. Phares. *Black walnut seedling production and related nursery research. Northeast. Area Nurserymen's Proc. (In press.)*

These figures are open to interpretation. My interpretation points to two related problems: (1) *Seed scarcity*. — Most States reported an inability to meet their production demands because of seed scarcity, particularly in 1970 and 1971. This scarcity was compounded by competition from the nut industry. The obvious question here is: Can we not provide nut storage so that we do not always have to depend on this year's nut crop for next year's seedlings? Surely the cost of storage is far less than the cost of not having seedlings. (2) *Technical assistance*. — On-the-ground technical assistance must accompany walnut planting programs in order to obtain quantity and quality. There has not been a significant increase in public or private service forestry positions in the field since 1966. And there have been increasing demands on the field forester's time from other facets of forest management. In short, we have superimposed the job of walnut planting and culture on an existing organization without provision for expansion.

*Exports*.—The export of walnut veneer logs continues, and we are not much closer to a solution, or even agreement among ourselves, than we were 7 years

ago. Exports have exceeded domestic consumption since 1967, and there is no export control program. Exports, however, have dropped from a high of 22 million board feet in 1968 to 13 million feet in 1971. Domestic consumption has declined also.

*The Small Woodland Owner*.—The key to the future of black walnut is the small woodland owner. He owns most of the resource, and whatever influences him influences the resource. His pressures are many — taxes, pollution, urbanization, and competition from the many other facets of our society. If we are to secure the future of walnut, we must continue to make walnut growing competitive with other land-use alternatives. But if we are to be truly successful, we must also come out of the woods and work to modify the other facets of our society that influence the woodland owner, and consequently the walnut resource.

In summary, I believe we have built a solid technical base for growing walnut. We know what to do. We are not doing it enough. We must also address ourselves to the problems of marketing, economics, and related aspects of our society. Perhaps then we can truly begin the long climb up the hill of quality.

# TIMBER DEMAND AND USE

**James E. Blyth**, *Principal Market Analyst*  
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**ABSTRACT.**—The use of walnut increased from 1933 to the mid-1960's, then probably peaked out between 1963 and 1968. The proportion of walnut logs used for veneer has been increasing during the last two decades while the proportion used for lumber has been declining. Most export logs are cut into veneer. The demand for walnut logs has varied considerably during the 1960's, but the general trend of log prices has been sharply upward. Rising prices with fluctuating demand indicate a scarcity of high-quality walnut, a need for more efficient and complete utilization of the walnut resource, and the necessity for reducing costs in domestic manufacturing of walnut products so they can remain competitive with substitutes and foreign products.

Records of the annual cut of walnut timber for all products are incomplete for recent years. However, the use of walnut increased from 1933 to the mid-1960's, then probably peaked out between 1963 and 1968. For the years in which a census of wood used in manufacturing was made, the quantity of walnut wood used for all products (including log exports) ranged from 29 million board feet in 1933 to 141 million board feet in 1965 (fig. 1). Although more than half of the walnut logs were manufactured into lumber in 1965, the proportion used for veneer increased significantly in the last two decades. Most export logs are cut into veneer.

## SAW LOG DEMAND AND USE

Sawmills producing walnut lumber are scattered throughout the natural range of walnut. Most of these mills saw less than 100,000 board feet of walnut lumber annually, but a few saw more than 1,000,000 board feet per year and are often integrated with a hardwood veneer mill or specialize in walnut products such as gunstock blanks. Sawmills receiving large amounts of walnut logs often sort them into saw logs and veneer logs and in some instances further segregate the logs for domestic and export markets.

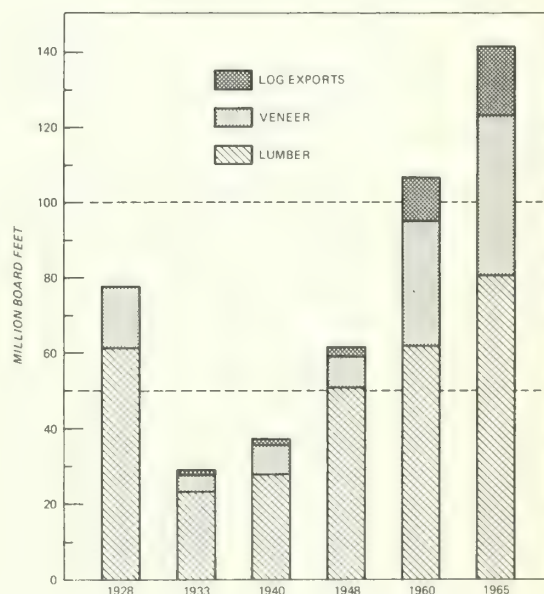


Figure 1. — Walnut wood use in selected years, 1928-1965; log exports: Scribner Decimal C log rule. Source: Lumber used in manufacturing 1928, 1933, 1940; wood used in manufacturing 1948, 1960, 1965; U S D A Forest Service and U.S. Department of Commerce export statistics.

From the sawmills, walnut lumber is shipped to furniture plants, other industrial plants, or overseas. In recent

years, walnut lumber exports and their average value per thousand board feet have been:

<i>Year</i>	<i>Lumber exports (Million bd. ft.)</i>	<i>Average value (Dollars per thousand bd. ft.)</i>
1962	5.4	405
1963	5.3	435
1964	7.6	398
1965	7.5	371
1966	8.7	390
1967	5.2	469
1968	4.9	489
1969	6.4	462
1970	6.9	429
1971	3.1	563

Source: U.S. Bureau of Census Annual Report FT 410

Although 1971 lumber exports were at the lowest level in a decade, the average value was the highest for that period.

Leading walnut lumber-producing States include Indiana, Missouri, Kansas, Ohio, Iowa, Kentucky, Illinois, West Virginia, and Tennessee. The censuses of wood used in manufacturing indicate that lumber use in manufacturing increased from 24 million board feet in 1933 to 80 million board feet in 1965.

A 1966 walnut logging utilization study in Indiana showed that 83 percent of the volume of saw logs harvested was growing stock<sup>1</sup> and 17 percent was nongrowing stock.<sup>2</sup> The saw log volume cut from nongrowing stock included 73 percent from trees on nonforest land, 16 percent from cull trees and cull sections, and 11 percent from limbwood. In addition, this study estimated that 19 percent of the walnut growing stock cut during saw log harvesting was left in the woods as residue. Based upon this study, a significant quantity of growing stock is not used, while nongrowing stock is apparently an important source of walnut saw logs.

<sup>1</sup> *Growing stock volume – net volume in cubic feet of sound wood in the boles of live sawtimber and pole-timber trees from stump to a minimum 4.0-inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Short-log trees are not included.*

<sup>2</sup> *Nongrowing stock – limbwood, saplings, cull trees, cull sections of growing stock trees, dead trees, and trees on nonforest and noncommercial forest land.*

## VENEER LOG DEMAND AND USE

Consumption of walnut veneer logs has varied greatly since 1961, depending upon domestic housing and furniture market strength, worldwide business conditions, and export regulations (table 1). At the same time, the average value has doubled for veneer logs purchased and export logs — an indication that high-quality logs are becoming scarce.

Walnut veneer log harvesting for domestic mills is concentrated in the North-Central Region<sup>3</sup> with significant quantities coming from the Northeast<sup>4</sup> and minor quantities from the South (fig. 2). The 1963 and 1968 harvest of walnut veneer logs for domestic use in selected States was:

<i>State</i>	<i>Quantity (Million bd. ft.)</i>	
	<i>1968</i>	<i>1963</i>
Illinois	3.0	2.3
Indiana	7.4	6.7
Iowa	3.4	4.5
Kansas	.9	4.5
Kentucky	2.6	2.7
Michigan	.5	1.2
Minnesota	.3	.3
Missouri	2.3	2.5
Nebraska	.2	.4
Ohio	2.2	4.2
Tennessee	.1	1.5
West Virginia	.6	.7
Wisconsin	.8	.4

Sources: USDA Forest Service Research Note WO-6, Resource Bulletins NC-10, NE-21, and SO-25; unpublished data from North Central and Northeastern Forest Experiment Stations, USDA Forest Service.

Indiana supplied nearly 300 out of every thousand board feet of veneer logs required by domestic mills in 1968. Many veneer mills, using large quantities of walnut, are concentrated in Indiana and nearby States.

<sup>3</sup> *Includes Indiana, Illinois, Iowa, Missouri, Kansas, Nebraska, Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota.*

<sup>4</sup> *Includes Ohio, Kentucky, West Virginia, Maryland, Pennsylvania, New York, Massachusetts, Connecticut, Delaware, Rhode Island, Vermont, Maine, New Hampshire, and New Jersey.*

Table 1. — Walnut veneer log consumption, exports, and average value for selected years, 1961-1972.

Year	Domestic : consumption	Average value of : logs acquired : per MBF	Quantity : exported	Average value of : exports : per MBF	Total : consumption <sup>2/</sup>
	Million : bd. ft. <sup>1/</sup>	Dollars per : thousand bd. ft.	Million : bd. ft. <sup>1/</sup>	Dollars per : thousand bd. ft.	Million : bd. ft. <sup>1/</sup>
1961	17.8	531	7.2	824	25.0
1962	22.4	586	10.3	961	32.7
1963	23.5	660	14.4	940	37.9
1964	19.8	719	9.6	1,105	29.4
1968	16.1	1,015	21.8	1,522	37.9
1969	12.4	1,108	20.8	1,519	33.2
1970	10.8	1,142	17.2	1,578	28.0
1971	10.2	1,167	12.9	1,666	23.1
1972	NA	NA	15.1	1,664	NA

<sup>1/</sup> Scribner Dec. C log rule.

<sup>2/</sup> Total consumption equals domestic consumption plus exports.

NA Not available.

Source: Office of Business Research and Analysis, Bureau of Domestic Commerce, U.S. Department of Commerce.

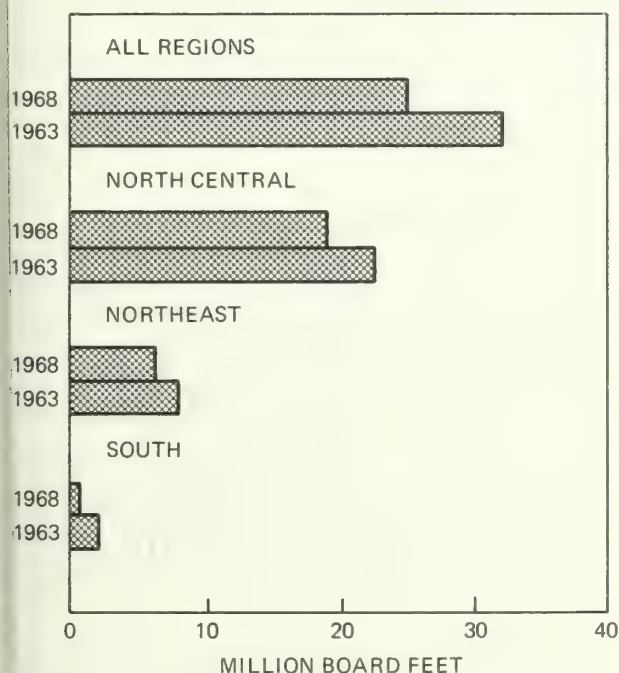


Figure 2. — Walnut log harvest by region for domestic veneer mills, 1963 and 1968; International 1/4-inch log rule. Source: USDA Forest Service Research Note WO-6, Resource Bulletins NC-10, NE-21, and SO-25.

In 1971 our export log volume was shipped primarily to West Germany (36 percent of total), Japan (19 percent), Canada (11 percent), Italy (11 percent), Brazil

(7 percent), and Switzerland (6 percent). Overall, European countries received 62 percent of the 1971 walnut log volume exported. In addition, the U.S. exported 97.7 million square feet (surface measure) of walnut veneer in 1971. The major importers of veneer were West Germany (66 percent of total) and Canada (27 percent).<sup>5</sup>

Some of our exports return as imports after processing. For example, in 1971 the U.S. imported 20.5 million square feet (surface measure) of walnut face plywood with a clear finish face; nearly all of it came from Japan.<sup>6</sup> Apparently the Japanese, using an efficient, relatively low-cost labor supply, are continuing to compete effectively with our veneer and plywood industry.

## SUMMARY

Overall, the demand for walnut logs has varied considerably during the 1960's, but the general trend of log prices has been sharply upward. Rising prices with fluctuating demand reflect a scarcity of high-quality walnut, a need for more efficient and complete utilization of the walnut resource, and the necessity for reducing costs in domestic manufacturing of walnut products so they can remain competitive with substitutes and foreign products.

<sup>5</sup> Export data from U.S. Bureau of Census Annual Report FT 410, 1971.

<sup>6</sup> Import data from U.S. Bureau of Census Annual Report FT 246, 1971.

# CHANGING RESOURCE AND UTILIZATION

**Glenn A. Cooper**, *Principal Forest Products Technologist*

**Eugene F. Landt**, *Principal Forest Products Technologist*

**Ronald D. Lindmark**, *Principal Economist*

and

**Harold A. Stewart**, *Forest Products Technologist*

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**ABSTRACT.**—Recent studies show that although the high-quality black walnut supply is diminishing, much untapped material is still available. The trees growing on nonforest land and logging residues can supply many of our needs. That low-quality material can be utilized has been demonstrated by woods residue recovery and conversion into products. Improved drying and machining techniques can increase efficiency of high-quality dimension part production, especially from low-quality raw material. Therefore, the manufacturer who practices close utilization can use the additional black walnut sources profitably.

High-quality black walnut is scarce, and the annual harvest continues to exceed the annual growth of high-quality timber. However, recent studies have shown that black walnut trees growing on nonforest land, and leftover material that is below current size and quality standards, add substantially to the overall black walnut supply. How best to use this untapped resource is a question facing the walnut industry.

Recent timber supply data indicate that more low-grade black walnut could be marketed if collection and processing of substandard size and grade material were feasible. Research has shown that high-quality dimension parts can be produced from low-quality material. The problem is not the quality of the wood, but the high production costs entailed in extracting lower yields and smaller pieces from the lower grade flitches and lumber. Hopefully, the demand for black walnut can offset higher production costs.

It appears that much low-value raw material could be utilized if processing was more intensive. Dimension processed from residue, improved machining of small parts, and improved drying systems for small pieces all promise to increase the yield of usable material.

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<sup>1</sup>The laboratory is maintained in cooperation with Southern Illinois University.

## THE RESOURCE

Several improvements in surveying the black walnut resource have been made since our last workshop 7 years ago.

The volume in short-log trees on commercial forest land and the volume in merchantable trees on nonforest land are now reported. However, because walnut is a minor species in every State in which it grows, resource data obtained by survey sampling are subject to wide statistical variation.

The most recent national data on the black walnut resource (USDA Forest Service 1972), released only a few months ago, do not differ greatly from those published in 1965 (USDA Forest Service 1965). Both sets of data account only for black walnut growing on commercial forest land.<sup>2</sup> The recent data indicate that black walnut growing stock volume is just under 1 billion cubic feet.<sup>2</sup> The geographic distribution of this resource is shown in figure 1. More than half the walnut is located in the central region, and an additional 35 percent is in the adjoining States of Kansas, Tennessee, Pennsylvania, and the Virginias.

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<sup>2</sup>See glossary on page 15 for forest survey definitions.

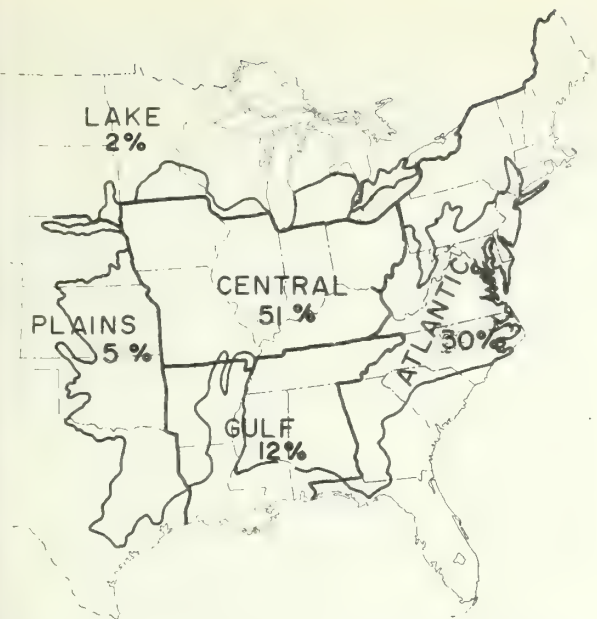


Figure 1. — The percentage distribution of black walnut growing stock volume by geographic region, 1970.

Since the previous surveys did not include short-log trees and completely ignored the resource on nonforest land, the more recent surveys have been designed to evaluate all sources of walnut.<sup>2</sup> One of the first surveys to evaluate wooded strips, fence rows, and pastures as sources of black walnut was conducted in Kentucky (Lindmark and DeBald 1969).

The Kentucky survey revealed that nonforest land and short-log trees added 33 percent to Kentucky's commercial forest resource. As expected, fewer than one-third of the open-grown, sawtimber-sized trees will yield a 16-foot log. About 25 percent had no usable bolt, and 11 percent contained only one 6- or 7-foot bolt.

The first State survey that included short-log trees on commercial forest land as well as the resource on nonforest land was done in Kansas (Chase and Strickler 1968). The short-log trees and growing stock on nonforest land added 41 percent to the growing stock volume and 25 percent to the sawtimber volume. Of the estimated 60 million cubic feet of walnut volume in Kansas, 9 million cubic feet were from nonforest land, and 9 million cubic feet were from short-log trees growing on commercial forest land. Approximately 83 percent of the total volume is considered merchantable. Total sawtimber volume approached 120 million board feet, of which almost two-thirds was in Grade 1 and 2 logs.

However, only 15 percent of the trees were larger than 19 inches in diameter.

The most recent resource survey in Indiana showed that black walnut growing stock remained relatively constant between 1950 and 1967 (Spencer 1969). Volume losses in the larger diameter classes were more than offset by gains in the smaller diameter groups. Thus, the total black walnut growing stock actually increased from 63 million cubic feet in 1950 to 65 million cubic feet in 1967. During this period sawtimber volume also increased slightly in the smaller diameter groups but decreased in diameter classes over 15 inches.

The resource not previously included in the Indiana survey — trees on nonforest land and those on commercial forest land containing only 8- to 11-foot saw logs — added 17 million cubic feet or 26 percent to the resource. A total of 41 million board feet was added to the sawtimber resource.

The various national and State surveys indicate that changes in black walnut growing stock volume have been slight. Some of these surveys have also determined that the black walnut growing on nonforest land adds a significant volume to our total walnut resource. Although the growth-cut comparisons for black walnut indicated a near balance in 1963, the annual cut of high-quality material exceeded growth by an estimated 47 percent (Quigley and Lindmark 1967). The more recent surveys also indicate that the volume of high-quality black walnut timber is declining. This is evidenced, in part, by a decline in the production of veneer logs in the Central States region (Blyth 1968, Ginnaty 1970, 1972). Along with this, there has been a noticeable increase in the price of walnut stumpage, although in Illinois prices have declined gradually from a peak reached early in 1972 (Illinois Cooperative Crop Reporting Service 1972, USDA Forest Service 1965).

How efficiently are we utilizing our walnut resource? A recent study in Indiana showed that for every 1,000 board feet of saw logs harvested, 182 cubic feet of black walnut timber were cut (Blyth *et al.* 1969). Of the volume utilized, 83 percent was from growing stock and the remaining 17 percent was from nongrowing stock, including limbwood, cull trees, and timber from nonforest land. Sixteen percent of the walnut cut was left in the woods as residue. The residue component included saw-log portions, upper stems, as well as cull tree material.

## IMPROVING BLACK WALNUT UTILIZATION

Black walnut utilization is changing as the supply of high-quality wood declines. Utilization methods have been modified to convert smaller and shorter logs than was common 20 years ago. Veneer manufacturers have successfully changed to thinner veneers than were formerly made. Drying operations have been improved to reduce kiln degrade, and more care in all phases of secondary manufacture is the order of the day. However, to augment the supply of black walnut for furniture parts, we need effective methods of processing non-commercial, low-quality residue material. We must learn how to salvage logging residue and process dimension cuttings from unmerchantable short-tree sections, short logs, tops, and large branches.

### Dimension from Residue

We made dimension parts from residue collected in southern Illinois to determine the yield and costs (Dunmire *et al.* 1972). The residue was bucked into 813

bolts 2 to 6½ feet in length and 5½ to 17 inches in diameter. The bolts were then live-sawed on a portable bolter saw into 1½-inch-thick rough flitches sawing through and through. Stacked flitches were air- and kiln-dried to 7 percent moisture content.

The bolts yielded about 75 percent of their International ¼-Inch Rule scaled volume in usable cuttings. If this percentage is based on the Doyle Rule, which is commonly used by the walnut industry, the yield values would be greater because the Doyle Rule scale volumes are about 50 percent lower than the International ¼-Inch Rule scale volumes for small diameter bolts. For all cutting lengths, recovery volumes of clear-one-side cuttings ranged from 85 percent of the International ¼-Inch Rule scale for clear bolts to 72 percent for bolts with no clear faces (table 1).

As expected, the cost of manufacturing dimension from residue is high. It took us from 1 to 4 hours of bolter saw time per thousand board feet, depending on bolt size. Subsequent rough milling required 8 to 23

Table 1. — Average black walnut dimension yields including sapwood based on International ¼-Inch Scale by cutting length classes from bolts of various grades

	:	:	:	:	:	:	Average			
	:	International:	:	:	:	:	total yield of			
Bolt	:	1/4-Inch	:	Dimension	:	Yield by dimension length classes:	International			
grade <sup>1/</sup>	:	Rule	:	cutting	:	:	1/4-Inch Rule			
	:	bolt	:	grade	:	:	bolt scale			
	:	scale <sup>2/</sup>	:	12-23 <sup>4/</sup>	:	24-47	:	48-78	:	volume <sup>5/</sup>
		Board feet		Percent of bolt volume				Percent		
C-4F	341	C-2S <sup>3/</sup>	19.5	47.0	16.8	83.3				
		C-1S & Better	17.9	48.3	18.6	84.8				
		CM & Better	16.1	49.9	19.0	85.0				
C-3F	725	C-2S	22.8	41.1	13.2	77.1				
		C-1S & Better	15.8	46.9	15.9	78.6				
		CM & Better	15.6	46.7	17.2	79.5				
C-2F	1,415	C-2S	22.0	36.7	12.7	71.4				
		C-1S & Better	19.9	39.4	13.6	72.9				
		CM & Better	17.6	41.1	15.4	74.1				
C-1F	1,838	C-2S	25.2	37.2	10.4	72.8				
		C-1S & Better	22.9	40.1	12.2	75.2				
		CM & Better	21.8	40.1	14.2	76.1				
C-0F	2,347	C-2S	29.7	32.9	7.2	69.8				
		C-1S & Better	27.3	36.8	7.9	72.0				
		CM & Better	28.5	36.0	9.6	74.1				
Average for all bolt grades	6,666	C-2S	25.5	36.6	10.4	72.5				
		C-1S & Better	22.9	39.9	11.7	74.5				
		CM & Better	21.5	40.9	13.4	75.8				

<sup>1/</sup> "C" refers to Clear and "F" refers to Face (1/4 of the bolt surface full length).

<sup>2/</sup> Doyle Scale volumes are about 50 percent less than the International 1/4-Inch Rule Scale volumes.

<sup>3/</sup> "C" refers to Clear, "S" refers to a top or bottom surface of a cutting, and "CM" refers to Character Marked, which includes some sound defects.

<sup>4/</sup> 12- to 23-inch class also includes cuttings 1- to 1-1/2 inches wide by all lengths.

<sup>5/</sup> Percent yield values based on the Doyle scale are about double the percent yield values that are based on the International 1/4-Inch Scale (i.e., the average Doyle based yield value for C-1S & Better for all bolt grades would be about 150 percent).

hours per thousand board feet (Dunmire *et al.* 1972, USDA Forest Service 1971). However, this high cost is offset first by the high yields and prices of dimension, and second by the steadily increasing demand for walnut products. A comparison between the estimated gross dollar return for the highest-grade bolts and the lowest-grade bolts shown illustrates that even low-grade bolts can give a high return (fig. 2). This should encourage the ingenious operator to attempt closer utilization and thereby benefit from residue that would otherwise be wasted.

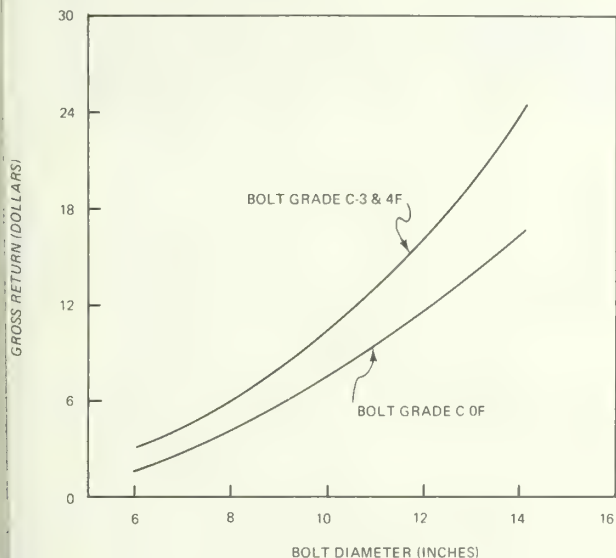


Figure 2. — Estimated gross dollar return per bolt for clear-one-side (C-1S) 4/4-inch-thick flat dimension from grade C-3 and 4F and C-OF black walnut bolts 4 feet long. The gross return was determined for different bolt sizes by using an average estimated selling price of \$1,000 per M board feet for the clear-one-side black walnut dimension with random widths and lengths.

Walnut residue, when converted to dimension cuttings, is suitable for a variety of consumer products. Furniture parts, picture framing, decorative plaques, bowls, and even paneling have been made from small parts edge-glued and finger-jointed. An important finding was that the properties and appearance of black walnut dimension parts are the same whether the parts are made from conventional lumber or converted from residue. Attractive, high-quality products can be made from the cuttings (fig. 3).

Production of black walnut dimension from standard lumber has not been neglected. The Forest Products

Laboratory in Madison, Wisconsin, developed charts for predicting dimension yields from the top four lumber grades (Shumann 1971). These yield data are valuable for furniture and dimension plant operators to use in grade selection, in determining grade mixes and costs, and for scheduling production time. With the charts it is possible to make yield and cost comparisons to achieve the greatest economy for a particular cutting order.

## Dimension Drying

An important processing step in producing usable black walnut material for further manufacture is drying. The complex interactions of black walnut wood fiber, extractives, and water have been studied in depth to help develop better methods of drying and stabilizing the wood. It is well known that the extractives in black walnut stabilize the wood against shrinking and swelling as moisture content of the wood changes. We found that drying lowered the moisture content at fiber saturation from 48 percent to 31 percent, and extraction lowered it to 28 percent moisture content. This showed that the extractives had a greater affinity for water (hygroscopicity) than the cell walls, and thereby altered shrinking and swelling.<sup>3</sup> This means we can alter wood properties by changing the relationships between extractives and cell walls using physical or mechanical means.

Research has shown that freezing is one way to change the role of extractives in wood, and it greatly benefits drying of black walnut. Freshly cut black walnut (at about 80 percent moisture content) is not damaged by freezing because there is sufficient void space in the wood to accommodate the expansion of water to ice. Freezing and then thawing before drying, called pre-freezing, increases the beneficial role extractives play during the drying process.

In studies of prefrozen black walnut, the drying behavior, shrinkage, strain and set development, moisture gradients and drying rate, drying defects, and changes in extractive availability were measured. When black walnut test specimens were frozen at six temperatures ranging from -10 to -320°F., shrinkage was reduced by prefreezing (Cooper *et al.* 1970). We found that induced shrinkage reduction and altered moisture affinity

<sup>3</sup>G. A. Cooper. The effect of black walnut extractives on sorption, shrinkage, and swelling. Unpublished manuscript on file at North Cent. For. Exp. Stn., Carbondale, Ill. 1972.



Figure 3. — *Small black walnut bolts produce high-quality dimension parts that are suitable for the manufacture of attractive products.*

resulted from the combined effects of prefreezing on increased extractives bulking and altered wood creep. The greatest effect was induced by prefreezing at -110 F.; storage time intervals after prefreezing did not affect shrinkage reductions (Cooper 1972). We also found that prefreezing of black walnut results in greater radial permeability of both the sapwood and heartwood.<sup>4</sup>

after prefreezing did not affect shrinkage reductions (Cooper 1972). We also found that prefreezing of black walnut results in greater radial permeability of both the sapwood and heartwood.<sup>4</sup>

These favorable responses to prefreezing indicate that we can improve the processing of dimension parts in several ways. First, because prefreezing increases permeability, the free water in wood can be dried out faster than without prefreezing. Second, increased permeability means we may be able to impregnate chemicals into prefrozen black walnut faster than into wood that has not been prefrozen. For example, stabilization with polyethylene glycol-1000 might be accomplished more readily if black walnut has been prefrozen. This is being investigated now. Third, because shrinkage is reduced, there are fewer shrinkage-related defects in prefrozen black walnut. Honeycomb and collapse are reduced significantly, particularly in thick stock. Prefreezing therefore holds promise for an improved drying system for high-value thick dimension, such as turning

squares and gunstocks, by decreasing drying time and drying defects.

## Machining Improvements

One problem in processing black walnut dimension parts into panels is that the glued up panels will have a variation in slope of grain. This can cause surface machining defects, such as chipped grain. Therefore, to get the maximum yield from low-grade material, we need planing methods that minimize the amount of subsequent processing and waste. Machining research at Carbondale has shown that two methods of planing reduce planing defects and waste (Stewart 1970a, 1970b, 1971). The first, abrasive planing, eliminates the conventional knife planing defects and requires only about 0.010 and 0.015 inch of subsequent sanding to produce a satisfactory surface for finishing. However, the waste from abrasive planing is sanding dust; if uses for the dust are not found, there is a disposal problem.

The second method, cross-grain knife planing, can be applied to panels not longer than the width of the cabinet planers. This may be as much as 52 inches. Thus, 4-foot-long panels could be cross-grain knife-planed. When cutting cross-grain, a cleavage failure does not advance along the grain ahead of the knife edge. Hence, chipped grain or tear out, even along glue lines, is minimal. The surface from cross-grain knife planing is generally as good as or better than a surface abrasive-planed with a 36-grit belt. In a trial at Carbondale a spray lacquer finish was satisfactorily applied to cross-grain knife-planed walnut panels without sanding. However, in practice a small amount of sanding would probably be required for an acceptable finish.

<sup>4</sup>P. Y. S. Chen and G. A. Cooper. *The effect of prefreezing on the permeability of black walnut to water.* Unpublished manuscript on file at North Cent. For. Exp. Stn., Carbondale, Ill. 1973.

Cross-grain knife planing of dimension stock can be done with segmented helical cutterheads.<sup>5</sup> The cuttings must be butted against each other and aligned so their long axes are parallel to a tangent of the helix cutters. The minimum distance (D) from the leading corner to the trailing corner of each cutting must be equal to or greater than the shortest stock that can be butted end-to-end when knife planing conventionally along the grain. Black walnut cuttings 1 by 10 inches (D = 4.39 inches) have been satisfactorily cross-grain knife-planed with a segmented helical cutterhead. The shortest stock that could be fed through butted was 4 inches. The cuttings were oriented side-by-side parallel to a tangent of the helix angle and followed by a longer cutting parallel to the feed to push the shorter cuttings under the cutterhead.

Other research showed that a high-quality particleboard can be manufactured from cross-grain knife-planed flakes (Stewart and Lehmann 1973). Low-density particleboard manufactured from such flakes meets or exceeds the minimum property requirements of medium- and high-density particleboard. Virtually all of the cross-grain knife-planed shavings, including black walnut, can be made into high-quality particleboards, thus reducing waste from the machining operation and stretching the raw material supply. A trial black walnut particleboard was produced from cross-grained black walnut flakes in cooperation with the Forest Products Laboratory at Madison, Wisconsin, to show that black walnut cross-grain knife-planed flakes can be used in particleboards.

## CONCLUSION

Recent survey information shows that significant additional sources of black walnut are short logs and trees in noncommercial forest land not reported in previous surveys. Also, to more completely utilize the total black walnut resource, improved processing methods have been developed. Production of walnut furniture dimension from low-quality material shows that an average of 75 percent of the International 1/4-Inch Rule scaled volume can be recovered in the form of high-quality dimension. A promising drying method for dimension parts made from low-quality timber is prefreezing the pieces before kiln-drying to significantly reduce drying time and rejects. After drying the material can be machined, using either abrasive planing or knife- cross-grain planing to reduce the chipped grain, thereby reducing waste in surface machining.

<sup>5</sup>H. A. Stewart. *Segmented helical cutters provide good residue for particleboard and reduce machining waste. Manuscript in preparation for publication.*

## GLOSSARY

*Commercial forest land.* — Forest land that is producing or is capable of producing crops of industrial wood and that is not withdrawn from timber utilization by statute or administrative regulation. Industrial wood includes commercial products such as saw logs and pulpwood, but excludes fuelwood and fence posts.

*Growing-stock volume.* — Net volume in cubic feet of sound wood in the boles of live sawtimber and pole-timber trees from stump to a minimum 4.0-inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs.

*Sawtimber volume.* — Net volume in board feet (International 1/4-Inch Rule) in the saw-log portions of live sawtimber trees from a 1-foot stump to a minimum 8.0-inch top diameter inside bark or to the point on the bole of sawtimber trees above which a saw log cannot be produced. A saw log is a log that is at least 8 feet long and meets the other standards of diameter and defect as specified for grade F1, F2, or F3 logs or for tie-and-timber class logs.

*Short-log trees (Special Kentucky Survey).* — Live trees 5.0 inches d.b.h. and larger that contain now or prospectively a usable 6- or 7-foot bolt. (*Indiana and Kansas Survey*). — Trees that contain one or more 8- to 11-foot saw logs and would qualify as growing stock except for the 12-foot log requirement. Although these trees are merchantable, the net volume is shown separately from growing stock.

*Nonforest land.* — Land that has never supported forests and lands formerly forested that are now developed for other uses. Includes areas used for crops, improved pasture, residential areas, city parks, and improved roads or power-line clearings of any width. If intermingled in forest areas, unimproved roads, trails, and nonforest strips must be more than 120 feet wide and clearings more than 1 acre in size to qualify as nonforest.

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# EVALUATION OF SELECTED WOOD PROPERTIES IN RELATION TO SOIL-SITE CONDITIONS

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**ABSTRACT.**—Relationships in black walnut wood color, specific gravity, extractive content, anatomical characteristics, machining, and mechanical properties were explored. The influence of geographic location, site quality, and growth conditions on these properties was also examined. Luminance was related to extractive content and to the combination of extractive content and some measure of wood density. Indiana trees differed significantly from Missouri trees by having: higher luminance value, lower extractive content, greater shrinkage, higher proportion of fibrous tissue with thinner cell walls, and smaller vessel lumens. No difference was detected in the physical characteristics or properties between trees from the two States.

It was 7 years ago that the first walnut workshop was held here in Carbondale, Illinois. The concern expressed then, I suspect, is the same now — what can be done to bring the supply of black walnut (*Juglans nigra* L.) lumber more in line with demand.

Specifically, the challenge issued by the keynote speaker, Ed Cliff, at that workshop still prevails as the charter of research efforts for all of us (USDA Forest Service 1966). Mr. Cliff alluded to three items of concern to meet the prospective needs for supplies of black walnut wood:

1. Stimulate diameter growth of growing stock trees.
2. Plant and grow superior type trees for timber.
3. Improve the wood quality of the growing trees.

It was the third point that motivated us in Wood Quality Research at the Forest Products Laboratory (FPL) to embark on a wood quality evaluation program for black walnut.

While forest managers the world over have accumulated considerable quantitative information on wood, it was not until the last decade that the need for qualitative information became evident.

The qualitative aspect, more appropriately referred to as timber quality, is by definition considered to be that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for its intended use. While such a definition may not be completely acceptable for all uses of wood, it does provide the framework for evaluating the quality of wood, based on its physical, mechanical, anatomical, and chemical characteristics.

Because no single unit expresses the quality of clear, straight-grained wood directly for all uses, wood quality is often described indirectly. That is, one or more properties of wood indicative of its suitability for a particular use is measured or assessed.

For the coniferous species, specific gravity or wood density has been the single index most evaluated by those concerned with an assessment of wood quality.

We have not been so fortunate when it comes to the hardwood species. The many and diversified uses, from pulpwood to furniture and paneling, have precluded development of a single unit to express the quality of wood. As a result, a number of factors or characteristics have been considered in our wood quality evaluations of black walnut.

At the previous workshop, it came to our attention that buyers of black walnut expressed a definite preference for logs from certain areas over others. The reasons for such preference are not definitely known. Some claim that defects such as bird peck, shake, and poor tree form are the main reasons for discrimination. Such defects may be more prevalent on trees growing near the borders of the species range or on poor sites. On the other hand, some think that discrimination by buyers of walnut logs from certain localities is from habit and without valid reason.

To shed some light on such preferences, we at the FPL embarked on a comprehensive research program on the quality of black walnut wood. The objectives of our studies were to determine whether differences exist in color and extractives, anatomical features, mechanical properties, and machining characteristics of wood from two different areas in Indiana and Missouri; from fast- and slow-grown trees; and from good and poor sites.

## SAMPLING PROCEDURE

Thirty-two trees were selected from Indiana and Missouri, distributed equally within these States by site quality and by growth rate in a 2 by 2 by 2 factorial design (table 1).

Between 8 and 13 feet above ground, a 5-foot-long bolt was cut from each tree, and the age of the tree (bolt) and diameter-growth rate determined on both ends of each bolt. Diameter inside bark, heartwood diameter, and sapwood width were also determined for two site and growth subclasses (table 2).

A sample of the surface soil (15 cm.) was taken from around each sample tree; each was the composite of eight borings taken systematically within a 6-meter radius of

the tree. A pit was also excavated, and the soil profiles described and classified at each location, including depth to mottling or impervious layer. The 5-foot bolts were sawn into 1¼ by 4¼-inch boards and from each bolt eight boards were randomly selected for the study. Following a light surface planing, each board was cut into four 1-foot-long pieces and one 6-inch randomly selected section. The 6-inch section provided the samples for determining color, wood structure, shrinkage, and extractive content. The 12-inch-long pieces were dried to 12 percent moisture content and provided the samples for the machining and strength tests.

## RELATIONSHIP OF WOOD COLOR TO SOIL PROPERTIES AND SITE

There has been very little information on the effects of specific environmental factors on heartwood color. There are two different views on the origins or movements of extractives to form heartwood. In one view it is believed that extractives are produced in the cambium or outer sapwood and translocated by the rays to the heartwood (Stewart 1966). In contrast, the other view is that extractives are formed *in situ* in sapwood cells that become heartwood cells (Hillis 1962, 1968). In either case, therefore, it was suspected that soil properties important for black walnut growth could affect wood color through their effects on the metabolism of the tree.

One of the first attempts at assessing the color characteristics of heartwood in trees from different geographic areas was by Sullivan (1967). He found significant within-species differences in the color properties of yellow-poplar and black cherry that were related to the geographic location of the trees. Moslemi (1967) at Southern Illinois University further demonstrated that differences in walnut wood color could be determined

Table 1. — Sampling design for black walnut trees

		Missouri			Indiana		
Site class	Growth class	Average Trees	50-yr. growth rate	50-yr. site index	Average Trees	50-yr. growth rate	50-yr. site index
		No.	Rings/cm.	Ft.	No.	Rings/cm.	Ft.
Good	Fast	4	3.3	60	4	2.8	80
	Slow	4	4.2	58	4	3.9	78
Poor	Fast	4	3.6	55	4	2.8	76
	Slow	4	4.2	57	4	4.1	67

Table 2. — *Values of bolt characteristics for black walnut trees from Indiana and Missouri<sup>1</sup>*

INDIANA						
Site class	Growth class	Diameter inside bark	Heartwood diameter	Sapwood width	Age	Growth rate
		In.	In.	In.	Yrs.	Rings/in.
Good	Fast	13.0	10.6	2.4	45	7.2
	Slow	10.9	9.4	1.5	70	12.9
Poor	Fast	15.2	12.2	2.6	52	7.2
	Slow	12.0	10.4	1.6	63	10.5
MISSOURI						
Good	Fast	13.7	12.0	1.7	55	8.3
	Slow	11.6	9.8	1.8	62	10.6
Poor	Fast	12.7	11.1	1.6	57	9.1
	Slow	11.0	9.5	1.5	58	10.6

<sup>1/</sup> The values are the average of four trees and represent the 8- to 13-foot aboveground portion of the tree.

by spectrophotometric analysis. Our work on black walnut began when Nelson *et al.* (1969) evaluated the color of heartwood samples, according to the International Commission on Illumination (I.C.I.) system. Spectrophotometric analyses were used to determine the following properties: (1) percent luminance — the brightness or lightness of the color, (2) dominant wavelength — related directly to the hue of the color, and (3) percent purity — percentage of principal hue in the color.

Results of this portion of the study conducted by Nelson indicated that greater differences between trees were found in luminance than in dominant wavelength and purity. Mean tree luminance was significantly higher for the Indiana-grown trees than for the Missouri-grown. The difference is pertinent because it may indicate a trend toward easily distinguishable luminance difference in walnut from more widely separated geographic areas.

Although the results did not reflect a significant difference between wood from sites of different quality, there were indications that on the poor sites the wood was lower in luminance and higher in dominant wavelength.

The relationships of the three color parameters with oil properties were evaluated by Nelson *et al.* (1969) and Maeglin and Nelson (1970) by regression analysis.

The analysis revealed variations in soil fertility were correlated with differences in wood color between individual sample trees. While the range of observed site quality was rather limited, the poorer sites showed a tendency toward darker, more red heartwood (lower luminance, higher dominant wavelength). In terms of simple linear regression analyses, pH consistently had the highest correlation with each of the three color values. In the two variable combinations this did not hold true, for in no case was pH included in the combination with the highest  $R^2$ . The relationship of pH in the simple regressions is believed to be related to the effect of pH on other soil properties that may directly affect wood color.

On the whole, mean tree luminance was most highly related to available P, exchangeable Ca, exchangeable Mg, and depth to mottling or impervious layer. These findings allow for the possibility of one day controlling wood color by manipulating the soil by fertilization or by other soil management techniques.

## RELATIONSHIP OF WOOD COLOR TO ANATOMICAL CHARACTERISTICS

Based on the same specimens used by Nelson in the color evaluation, Hiller *et al.* (1972) determined whether

the differences in color observed by Nelson could be related to specific gravity, structure, or extractive content of the wood. A second objective was to determine whether growth rate and site class affected the physical and anatomical characteristics of black walnut. While very little appears in the literature on these effects (Dilow and Hawker 1971, Boyce *et al.* 1970), the inverse relationship of shrinkage to extractive content is well known (Cooper 1971, 1972).

The structural features examined by Hiller *et al.* included:

- Percentage of area occupied by vessel lumens.
- Percentage of area occupied by normal fibers.
- Percentage of area occupied by gelatinous fibers.
- Average number of vessels per mm.<sup>2</sup>.
- Average vessel lumen area (mm.<sup>2</sup>).
- Cross-sectional dimensions of the fibers.
- Percent extractives.
- Specific gravity of fibrous tissue.

The amount of extractives based on the specific gravity specimens (end matched to color and wood structure) was determined by the TAPPI standard method (1959) and expressed as a percentage of the extractive-free weight of the wood. Specific gravity was determined from the extractive-free oven-dry weight and the volume of the specimens in the water-saturated condition.

Single and multiple linear regression analyses were used to determine the relationships between the wood color parameters and the structural features mentioned previously.

Results of analyses based on values for individual test specimens and on average values for bolts were essentially the same. Dominant wavelength and percent purity were not significantly related to any single variable (structural features) or to any combination of variables. The third dependent variable, percent luminance, was, however, significantly related to percent extractives and to the specific gravity of the fibrous tissue, or other measures of wood density.

The results further indicated that wood from Indiana had lower percent extractives than that from Missouri. In addition, the following differences in wood characteristics between the States were found:

Trees from Indiana had thinner cell walls.

Trees from Indiana had a lower percent cross-sectional area occupied by vessel lumens.

Trees from Indiana had smaller average vessel lumen areas.

Wood from the two States did not differ in gelatinous fiber content nor did the regression analyses show any relationship between that characteristic and the color of the wood. In this regard it is interesting that when States are ignored, the wood from good sites had significantly more gelatinous fibers than the wood from poor sites. Similarly, wood from the slow-growing trees had a significantly higher percent of gelatinous fibers than did the fast-growing trees.

Nelson *et al.* (1969) found a relationship between wood color and some soil properties; it is interesting to speculate that soil properties might also affect the extractive content of wood. Because extractive content is negatively related to the shrinkage of wood, it may be the factor of greater importance for the industry. It may also be possible in the future to control not only the color but also the shrinkage characteristics of wood by controlling forest management practices.

## MECHANICAL, PHYSICAL, AND MACHINING PROPERTIES

This portion of the study, conducted by Schumann (1973) was also based on wood specimens from the sample of Nelson *et al.* (1969). The objective was to determine whether the anatomical characteristics measured by Hiller *et al.* (1972) were related to the machining and mechanical properties of wood. The machining tests conducted by Schumann were associated with planing, shaping, and turning; and the mechanical properties evaluated were hardness and toughness. Three physical characteristics — shrinkage, slope of grain, and specific gravity — were also examined.

Volumetric shrinkage, based on dimensions of the sample when green and when dried to 12 percent moisture content, was greater in the Indiana-grown black walnut (table 3).

Extractive content and volumetric shrinkage were significantly and negatively correlated. That is to say, the Indiana material, with its higher luminance value and lower extractive content, exhibited greater shrinkage than the Missouri samples.

Table 3. — Means and differences of mechanical and physical properties of black walnut by State of origin, site class, and growth rate. Each value is the average of 16 trees

Classification :	Extractive : content	Volumetric : shrinkage <sup>1/</sup>	Specific : gravity <sup>2/</sup>	Hardness :	Toughness:	Slope of grain
	Percent	Percent		Pounds	In.-Pounds	Percent
State:						
Indiana	5.3	5.14	0.556	1,154	251.9	6.7
Missouri	6.6	4.75	.560	1,131	239.9	4.3
Difference	<u>3/</u> 1.3	<u>4/</u> .39	.004	23	12.0	<u>4/</u> 2.4
Site quality:						
Good	5.5	5.05	.563	1,172	272.7	5.1
Poor	6.5	4.84	.554	1,113	219.0	5.9
Difference	1.0	.21	.009	59	<u>4/</u> 53.7	.8
Growth rate:						
Fast	6.2	5.00	.565	1,170	247.7	5.4
Slow	5.7	4.90	.551	1,115	244.0	5.6
Difference	.5	.10	.014	55	3.7	.2

<sup>1/</sup> Based on dimension when green and then dried to 12 percent moisture content.

<sup>2/</sup> Based on volume at 12 percent moisture content and oven-dry weight.

<sup>3/</sup> Difference significant at 0.05 level.

<sup>4/</sup> Difference significant at 0.01 level.

The slope of grain was greater in the Indiana specimens, but the amount did not appreciably affect any of the machining or mechanical properties. In both Indiana and Missouri, the good sites produced tougher wood, which was correlated with specific gravity and extractive content. An increase in specific gravity and extractive content will, therefore, correspondingly reflect an increase in toughness.

Shaping and turning tests indicated that geographic location, site quality, and growth rate did not affect the quality of the specimens. Similarly, none of the anatomical or physical characteristics affected the quality of the resultant shaping and turning specimens. All specimens machined well.

Specific gravity proved to be the one most important characteristic in evaluating machining and mechanical properties of black walnut. As pointed out by Schumann (1973), it accounted for 45 percent of the variation observed in the hardness values, 8 percent of the variation in toughness values, and 9 percent of the variation in planing. Specific gravity was also correlated with volumetric shrinkage and slope of grain.

## SUMMARY

The reasons that black walnut wood from one area is preferred to that from another area were partially explained by the intrinsic characteristics measured in this detailed study.

Of the three color parameters measured, larger differences were found in heartwood luminance than in dominant wavelength or purity. Indiana-grown walnut heartwood had higher luminance than Missouri-grown. Luminance was significantly related to extractive content and specific gravity. Extractive content and volumetric shrinkage were significantly and negatively correlated. The Indiana material had higher luminance, less extractives, exhibited greater volumetric shrinkage, had thinner cell walls, and smaller vessel lumens than the Missouri-grown walnut.

Regression analyses indicated that variations in soil fertility were correlated with differences in wood color between individual sample trees. Available P, exchangeable K, Ca, Mg, total N, and pH were found to be most important in relation to color variation.

While no differences were found in mechanical properties between trees from the two States, a significant difference was found between sites. Specimens from the good sites had substantially higher toughness values than those from the poor sites. No difference in hardness was detectable among States, sites, or growth conditions.

Specific gravity was the important characteristic in evaluating the machining and mechanical properties of black walnut. It accounted for 45 percent of the observed variations in hardness values, 8 percent in toughness values, and 9 percent of the variation in planing.

The results suggest the possibility of controlling the desirable characteristics by manipulating forest management practices and by improving the quality of black walnut through genetic means.

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# FEDERAL TRADE COMMISSION GUIDES AND THEIR EFFECTS ON THE CONSUMER

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**ABSTRACT.**—Walnut and fine hardwoods consumer products now protected by Federal Trade Commission Guides are described. The Guides are interpreted, and the enforcement policies are explained; the consumer products still urgently in need of similar regulations are mentioned. Association activities in furniture case goods surveys and tag and label promotions are also described.

The phrase, "consumer protection," is a much used and much needed part of today's scene. From the Federal government on down, divisions, agencies, and bureaus have been established in order to provide the consumer with a fair deal on his purchased commodities or services. As is usually the case with something new, a variety of things have been overemphasized; but perhaps more important, some consumer goods which have been underemphasized are finally being recognized as demanding immediate corrective action.

Actually, to pinpoint this need, "consumerism" (for want of a better word) has replaced ecology as a major issue for 1973. This is borne out by a recent poll of public relations directors of large corporations which disclosed that nearly 50 percent of the commercial, industrial, and consumer respondents are planning major government relations programs as part of their 1973 budget, a decided increase over 1972.

One of the agencies now recognizing these needs is the Federal Trade Commission, Washington, D.C. Among its many fields of activity was the Decorative Wall Paneling Industry and its own particular need for "guidance concerning legal requirements applicable to this industry in the interest of protecting the public and effecting more widespread and equitable observance of the laws administered by the Commission."

Hence, after a full public hearing held on March 12, 1970, the Commission adopted Guides for the Decorative Wall Paneling Industry on December 15, 1971, which were to become effective 1 year later. This provided 1 entire year for members of the industry to

acquaint themselves "with a sufficient number of examples to afford them meaningful guidance in the conduct of their affairs so as to avoid legal difficulties."

The intentions of these guides and others to follow — namely, Guides for the Household Furniture Industry — are to ensure against the prospective purchaser being misled by the appearance of a product, or by descriptions, designations, advertising, labeling, or other promotional means, into thinking the product is different from that which is actually offered. In summary, all guides may be brought under the Federal Trade Commission Act, which makes it illegal for one to engage in unfair methods of competition and unfair or deceptive acts or practices in commerce. Copies of guides and interpretations can be had on request from the Division of Rules and Guides, Bureau of Consumer Protection, Federal Trade Commission, Washington, D.C. 20580.

Examples of representations considered false in the Guides for Decorative Wall Paneling are:

1.—Describing a particleboard, flakeboard, hardboard, fiberboard, chipcore or plywood panel as "solid wood."

2.—Describing as "natural wood grain" a simulated grain design which has been printed on, attached to, or simulated in any other manner on the surface of an industry product.

3.—Describing a nonlumber product, such as particleboard, hardboard, fiberboard, flakeboard, and products of similar composition, as "wood." Although

such products are composed of wood particles or wood fibers, they should not be represented without qualification as "wood" but may be described as "particleboard," "hardboard," "fiberboard," "wood product," or by any applicable nondeceptive word or term.

4.—Describing as "walnut," "in walnut," "genuine walnut," "walnut panel," or "walnut plywood" a panel having only a face veneer of walnut. Proper descriptions would include "walnut veneer face," "walnut veneer surface," "walnut veneer," or "walnut veneered plywood."

5.—Describing as "walnut veneer" a panel having a face veneer not entirely of walnut. If a wood name is used to describe a panel having more than one kind of wood in the face veneer then all of the woods in the face veneers should be named or otherwise identified (e.g., "walnut and cherry veneers" or "walnut and other hardwood veneers").

6.—Using unqualified phrases such as "wood-pattern" or "woodgrain finish" to describe a panel having a wood surface which has been stamped, rolled, pressed, or otherwise processed in such manner as to change the natural wood grain design. Proper descriptions would include "simulated woodgrain finish," "imitation grain figure," or "simulated walnut grain finish on birch face veneer."

7.—Has an exposed surface of plastic, metal, vinyl, hardboard, particleboard, or other material not possessing a natural wood grain structure but which has an appearance simulating that of a wood grain. Depending on the composition, proper descriptions would include "simulated walnut finish on plastic face," "vinyl surface with simulated pecan finish," "simulated birch finish on hardboard," "mahogany grained plastic," or other nondeceptive phrases.

8.—Has a wood surface finished by means of staining, decalcomania, printing, paper coating, or other process so as to have the appearance of a different kind of wood. Depending on the composition, proper descriptions would include "mahogany finished gum plywood," "walnut stained plywood," "walnut finish on pecan veneer face," or "cherry grain design on hardwood plywood."

Also, under the "Deceptive Use of Wood Names" section, please note the following: "The unqualified term 'walnut' should not be used to describe wood other than genuine solid walnut (genus *Juglans*). The

term 'black walnut' should be applied only to the species *Juglans nigra*."

Under the section entitled "Imitations of Materials Other Than Wood," this should be noted: "A hardboard panel having an imitation marble finish should not be described without qualification as 'marble,' 'onyx,' 'travertine,' or 'travertine marble finish.' Proper descriptions would include 'simulated marble finish,' 'imitation marble-textured,' 'marble pattern on plastic faced hardboard,' 'simulated travertine or hardboard,' 'marble pattern on vinyl-faced hardboard,' or other nondeceptive terms."

And finally, paneling industry members should not: "(a) remove, obliterate, deface, change, alter, conceal, or make illegible any information these Guides provide be disclosed on industry products, without replacing the same before sale, resale, or distribution for sale with a proper mark or label meeting the provisions of these Guides; or (b) sell, resell, or distribute any industry product without its being marked or labeled and described in accordance with the provisions of these Guides."

All of the above violations if ignored and continued, place the violator subject to severe daily fines, imprisonment, or both. In addition to their Washington headquarters, the Federal Trade Commission has district offices in most major cities. Their personnel, after December 15, 1972, are prepared to enforce the law wherever established violations have been reported. These are the effective ways and means FTC Guides will be and are being endorsed.

Now that Mr. and Mrs. Consumer know what they are purchasing in wall panels, what other consumer goods desperately need similar effective insurance against wood imitations? Obviously, household furniture, cabinets, and home entertainment items come to mind. To this end, the Federal Trade Commission has before its Board of Commissioners similar guides pertaining to household furniture that contain similar language and similar case violations to those listed in the guides for wall paneling. Many manufacturers define their wood imitations properly, but after bedroom and dining room suites reach the retail floor, these identifications seem to mysteriously disappear.

For the last 39 years, our Association has tallied every bedroom and dining room suite shown at the two most important international furniture markets — usually April and October (tables 1 and 2). This survey

Table 1.—Southern Furniture market survey, bedroom and dining room suites, October 1971 and 1972.

BY WOODS					
Wood or style	Number of suites		Percentage of total		Percentage change
	1971	1972	1971	1972	
Walnut S & V <sup>1/</sup>	253	202	9.5	7.7	-1.8
Mahogany S & V	73	50	2.7	1.9	-.6
Cherry S & V	210	113	7.9	4.3	-3.6
Maple S & V	273	231	10.2	8.9	-1.3
Oak S & V	297	349	11.1	13.4	+2.3
Butternut S & V	3	34	.1	1.3	+1.2
Pecan S & V	380	347	14.2	13.3	-.9
Birch S & V	50	42	1.9	1.6	-.3
Pine S & V	158	172	5.9	6.6	+.7
Prints & plastics	609	717	22.8	27.4	+4.6
Painted	260	271	9.7	10.4	+.7
Other solids <sup>2/</sup>	28	20	1.0	.8	-.2
Other veneers <sup>2/</sup>	79	62	3.0	2.4	-.6
Total	2,673	2,610	100	100	

BY STYLES					
Modern	--	--	17.4	18.5	+1.1
Commercial modern	--	--	.6	2.0	+1.4
Total modern	--	--	18.0	20.5	+2.5
Provincial	--	--	7.6	5.8	-1.8
Court	--	--	3.3	1.0	-2.3
Total French	--	--	10.9	6.8	-4.1
Early American					
Colonial Federal	--	--	26.8	27.4	+.6
Italian	--	--	13.8	5.8	-8.0
Spanish	--	--	26.6	34.2	+7.6
English	--	--	3.8	5.3	+1.5
Miscellaneous	--	--	.1	--	-.1

<sup>1/</sup> S = solids; V = veneers.

<sup>2/</sup> Includes: elm, prima vera, rosewood, teak, avelire, acacia, ash, sycamore, paldao, gum andiroba, bamboo, olive burl, poplar, persimmon, ebanwood, mozambique, cordia, wenge, and others not listed separately.

is all-embracing, as it covers every showroom in the market area. It provides three elements: wood species, style, and finish. If you will note the percentage of "Prints and Plastics" as higher than "Pecan and Oak" combined, you will then realize the necessity for truthful identification of these wood imitations. It gives real cause to wonder just how many consumers are positive they purchased the genuine, when they actually are the possessors of a paper print on a particle-board base. For the past 40 years the Association has also publicized and promoted its "hang-tag" program to assist the purchaser of genuine walnut products (fig. 1). Little good these tags do, which we sell to the manufacturer, if they are removed before the product is sold to the consumer.

Fortunately for all, the promulgating of the proposed Household Furniture Guides by the Federal Trade Commission will be the effective means to stop these deceptions. It is one of the prime objectives of the Fine Hardwoods-American Walnut Association to make every effort to see this accomplished. We feel everyone should describe any product truthfully, tell the public what it is, and identify its construction with a label or tag which legally cannot be removed. Then and only then will the consumer be afforded an honest choice of either the genuine or the imitation.

Table 2.—Southern furniture market survey, bedroom and dining room suites by wood finish, October 1971 and 1972.

(In percent)				
Finish	WALNUT			
	Bedroom suites		Dining room suites	
	1971	1972	1971	1972
	<u>1/</u> (119)	<u>1/</u> (99)	<u>1/</u> (134)	<u>1/</u> (103)
Dark	7.6	4.1	10.4	17.5
Walnut brown	56.3	43.4	56.7	36.9
Fruitwood brown	5.1	11.1	6.0	10.6
Light brown	16.0	11.1	11.2	7.8
Grey brown	2.5	1.0	--	--
Tan and honey	1.7	3.0	3.7	3.9
Red brown dark	10.9	26.3	11.2	23.3
Other natural wood tones	--	--	.8	--

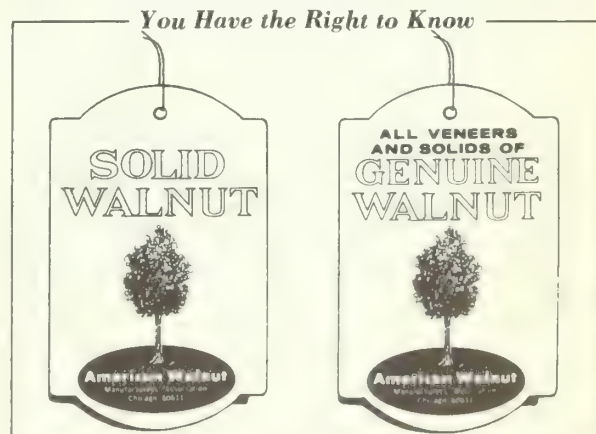
  

OTHER WOODS				
	<u>1/</u> (1056)	<u>1/</u> (740)	<u>1/</u> (755)	<u>1/</u> (680)
Dark	19.9	17.8	15.9	18.5
Walnut brown	20.1	21.5	13.9	14.1
Fruitwood brown	17.1	25.1	19.3	16.0
Light brown	23.0	11.8	12.9	19.1
Grey brown	4.1	5.7	2.2	.8
Tan and honey	10.3	9.5	22.1	18.3
Red brown dark	4.6	6.9	11.2	10.9
Other natural wood tones	.9	1.7	2.5	2.3

PRINTS-PLASTICS				
	<u>1/</u> (379)	<u>1/</u> (462)	<u>1/</u> (230)	<u>1/</u> (255)
Dark	12.8	32.0	10.4	13.7
Walnut brown	26.6	24.0	12.6	19.6
Fruitwood brown	18.6	14.9	27.4	25.1
Light brown	22.9	13.6	15.2	22.8
Grey brown	7.9	3.0	8.7	--
Tan and honey	8.4	6.3	13.9	9.0
Red brown dark	1.0	1.5	11.3	3.9
Other natural wood tones	1.8	4.5	.5	5.9

1/ Numbers in parenthesis = number of suites.



Trade names which contain the word "walnut" may be misleading. There may be less walnut in the piece than you suppose, says a leading designer. Read information tags, such as those above, with care, he continues, because you have the right to know.

Tags which read "Solid Walnut" indicate that all exposed parts are solid wood. Tags which read "Genuine Walnut" mean that exposed parts are walnut veneers and walnut solids. If the furniture is not tagged, insist on information about the materials used in the piece. Both tags shown assure you that the furniture contains no printed imitation grains.

Figure 1.—Examples of tags used on walnut products to protect the consumer.

# FOREST PRODUCTS REGULATORY LEGISLATION

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**ABSTRACT.**—The intent of the Illinois Timber Buyers Licensing Act is to protect the landowner's right to receive monies due for timber sold, and to protect against timber piracy. The law requires anyone buying timber from the timber owner to be licensed. To obtain a license a surety bond must be posted. Amount of bonding surety is based on total timber purchases. Anyone transporting two or more logs or Christmas trees on any road in Illinois may be required to show proof of ownership under provisions of the Forest Products Transportation Act.

The Licensing Act has been on the books for a period of 5 years. From its original form it has undergone considerable change. The biggest change was 2 years after its original passage.

The original Act was written by the Illinois Agricultural Association, which does not have a forester. It did not license the small timber buyer but rather required the licensing of only timber buyers with three or more employees. Thus, over half of the timber buyers in Illinois were not required to post a bond and be licensed. Most of the problems regarding nonpayment for timber purchased developed within the ranks of these "smaller" buyers.

That law was not only ineffectual but, in the opinion of our Department lawyer, unconstitutional. The Division of Forestry took it upon itself to completely rewrite the statute in its present general form. We did request (and our recommendations were passed) some amendments to the law this year. Most of these amendments were points of clarification. The most potent amendment provided that lands adjacent to the purchase area were covered by the bond of the licensee. Without this amendment, buyers or loggers cutting over the line were not jeopardizing their bond or license.

The average timber owner sells timber only once or twice during his lifetime. Consequently, he is not familiar with the market or the pitfalls that can beset him. The intent of this statute is to protect the landowner's right to receive monies due for timber sold, and to protect him against timber piracy.

Simply stated, the law requires that anyone buying timber in Illinois after January 1, 1970, (from the owner or his representative) be licensed by the Department of Conservation. This is true of buyers living in the State as well as out-of-State buyers. Timber does not include firewood, Christmas trees, fruit or ornamental trees. The person who occasionally purchases timber for his own use and not for resale does not need a license. For instance, a farmer who buys some trees or logs to have sawed into drags, fencing, siding, etc., for use on his farm would be an occasional purchaser.

Cooperation and support of the primary wood-using industry has been excellent. Objections have been minimal — fewer than we anticipated. When an objection is aired, the intent of the law is explained to the buyer. After this he generally becomes a staunch supporter not only of the law but of our forestry programs.

This "getting with the program" has been a very definite side benefit of the law. It has drawn buyers, cutters, and others into our offices, thus expanding our contacts with these people, usually to their benefit.

To obtain this annual license a buyer must:

1. Make application.
2. Pay certificate and filing fees of \$30.
3. Supply bonding surety in the amount of 10 percent of his total timber purchases for the preceding year (minimum \$400, maximum \$10,000).

The bonding requirement is the real "meat" of the license. Bond can be supplied by either:

1. Surety bond (average cost \$20 per \$1,000).
2. Bank certificate of deposit (interest paid to timber buyer).

The buyer's bond is available to make restitution to timber owners who are not paid the agreed price for timber purchased. Here the key word is *agreed*. As long as the buyer pays the agreed price and cuts only the timber bought, the requirements of the Licensing Act are satisfied. We do not establish prices, or guarantee any other agreements of the sales contract under this law.

There are built-in protections for the timber buyer's rights also. We must give written notice of any violation or noncompliance. He has the right to request a hearing to present his side of the story. Only after these steps can we request the Attorney General to institute proceedings to have the buyer's bond forfeited.

Besides having his money (surety bond or certificate of deposit) on the line, there are some real teeth in the law. Conviction of violating any of the Act's provisions can mean a fine of not less than \$100 (up to \$1,000), or imprisonment of not more than 6 months, or both.

To date we have had 65 arrests. Enforcement and actual arrests are handled by the Department of Conservation's Division of Law Enforcement. Our field personnel cooperate with these law officers by supplying any technical assistance needed, information on buyers, and leads on violators.

We think we now have a fair and equitable law that can be used to ferret out the unscrupulous element of the timber industry. Once this is done, public confidence will be restored in the timber industry.

## FOREST PRODUCTS TRANSPORTATION ACT

The Forest Products Transportation Act was passed by the last legislative session on our recommendations. Principally it was aimed at walnut pilferage, although it will be a useful tool in all timber thievery cases. For instance, 2 weeks ago a complete 80-acre tract, absentee-owned, was completely cut over by a timber thief. Even if the cutter who stole this timber had been stopped, there would have been no law or regulation (ICC does not cover the transportation of rough wood products) requiring this man to prove ownership, or even divulge where he was getting the logs.

## ILLINOIS TIMBER BUYERS LICENSING ACT

In Illinois the public had developed attitudes toward the timber industry that could no longer be ignored. We must admit that there was solid justification for the poor image the industry had. Complaints of timber buying malpractices were a common occurrence in our office.

The ways of "skinning" the timber owner were as numerous and varied as there were timber buyers, or so it seemed. Not uncommon were such malpractices as the "cut now — pay later" operator (he cuts the timber and is supposed to return with the owner's money when he is paid at the mill — often he does not return), and accidentally on-purpose over-the-line cutting. Then, of course, we don't want to forget the out-and-out stealing of timber.

The Timber Buyers Licensing Act was a tool put in our hands by the legislature to stop these practices. We have had a marked degree of success. Administration and enforcement of the law began on January 1, 1970. Since that time, 25 complaints have been lodged against the 400-plus yearly licensed buyers.

# THE SIGNIFICANCE OF LOG AND TREE GRADING SYSTEMS

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**ABSTRACT.**—Everyone who owns or plans on owning a walnut tree is interested in the value of that tree. Black walnut value may be measured by the nut production, the rate of tree growth, the shade it provides, or eventually the products it yields. Value is generally measured by tree or log grades, which for practical purposes are the same. Almost every manufacturing plant has its own grade rule that has been developed through experience.

The number, type, and location of defects are common to all grading systems. Defects generally fall into two categories: those that are natural or caused by some external force upon the tree, and those that are created by man in his manufacturing or processing of the tree. Understanding defects and their importance to the manufacturing of the final product will help the timber landowner better understand the value of his resource and will guide him toward using the proper forest management practices.

All of us present today have an interest in black walnut, in one way or another. If there is one item that we might agree upon, it probably is that we all want quality in the walnut product of our interest. Some of you are more interested in growing and managing walnut for scientific purposes. Others may be more interested in the tree's nut crop. And, of course, others are interested in the wood products the tree produces. We also share an interest in the economics of the tree and its products. I recently heard that a number of trees in California that had been excellent nut producers were placed on the market for their wood because they had ceased to provide the nut crop for which they had been planted. This wood, however, will find a ready market in the lumber and gunstock industries and will continue to be of benefit to man long after the intended use of the trees has ended. We know that the trees we plant and grow today should eventually provide wood products for our use. We want these products to be of the highest quality. It stands to reason, therefore, that anything we can do now to improve future quality is really a move in the right direction.

I've been asked to talk a little about tree and log grades. Essentially, there is no difference between standing tree and log grades. This is only true, however, if the cutter makes the cuts at the same places in the tree as the buyer had envisioned when he measured and scaled the tree. I recall a story related by forester Eldon Heflin of our Department concerning a landowner he had worked with. A buyer had mentioned to this man that his company bought veneer logs down to 6 and 7 feet long. While this is true, the longer logs are much preferred and bring more money. This landowner proceeded to cut up some 40 good trees into 6- and 7-foot lengths. A beautiful 12-foot veneer log was cut into two 6-foot lengths. This sale should have brought him about \$3,000, but he ended up with slightly less than \$500. Since the walnut cutters and the buyers work closely together, we feel it's very much to the landowner's advantage to let the buyer bring in his own cutter to get the best products possible from the trees. Actually, this is a manufacturing problem and the buyer will scale the tree for its highest value. The cutter must cut the tree to the same specifications to maintain the highest value.

The manufacturers of walnut products have developed different grading systems over the years. Unfortunately, there is no single system that satisfies everyone in the industry, because each manufacturer can use different materials depending on its product. The systems in use today vary considerably; some employ alphabetical grades, some use numerical ratings, and some use a combination of the two.

The terms "grade" and "value" in dealing with walnut are almost synonymous. Some companies in the walnut business apply a price rather than a grade to a tree. Others use a grade system of the type I've mentioned, and then relate this grade to a price. What this all boils down to is that the manufacturers know through experience just about what they can get out of a tree of a certain size. They also know that if the tree has defects, they will get less than the full volume of material. They figure the loss due to defects, their costs and profit, and arrive at a value for the tree or log. The company must make a profit to stay in business. I want to add, however, that they sometimes get fooled on quality and lose money on a particular sale or group of logs. It is necessary, therefore, that they make this up on other sales so that they average out in the black. You really don't know what's inside a log until you open it up, and by then it's too late to do anything about what it has cost you. By making a profit, of course, the industry is able to assure landowners that it will be there to buy their trees when they reach maturity.

Each type of walnut manufacturer is able to utilize a somewhat different type of walnut. The market for veneer today requires relatively straight-grained material in lengths 9 feet and longer. Sapwood in the veneer industry is generally considered a defect. The lumber and furniture industries use lumber grades from FAS down to #2 Common, and because lumber is almost always steamed to darken the sap, sapwood is not a defect. In gunstock manufacturing no steaming is allowed because it destroys the color contrasts. Only limited sapwood is allowed. Incidentally, the

fancy gunstocks come from portions of the tree where lumber and veneer are not normally obtained, such as a crotch, burl, or the stump.

Because the industry uses tree and log grades to determine the amount of useful material they will get out of a particular tree or log, the number of defects is all-important. The common ground of all grading systems is the identification of defects and the location of these defects in the particular tree or log.

As I mentioned earlier, defects vary according to the needs of the manufacturer. We might define a defect simply as unusable material. I break defects into two general groups: (1) those that are in the log or tree, including natural and man-caused defects, and (2) those that man creates by mis-manufacturing.

Let's discuss the first group first because it is the largest. Natural defects include such things as unsound knots, sound knots, ring shake or separation, sapwood in some cases, deadwood, rot, tension wood, color variation, splits, and bird peck. Also included are defects caused by such things as fence wire, glass insulators, spikes, and gate hinges that man has decorated the tree with. Man also occasionally damages the tree with mechanical equipment or by fire, both of which later become defects or contribute to defects.

The second group, manufacturing defects, includes such things as cutting to incorrect lengths, splitting the tree, pulling fibers or splinters from the center of the log, allowing the log to lie in the woods too long where rot can start, and all of the associated defects from drying both in the log and in the products. These are generally splits and checks, warp, bow, crook, and honeycomb.

I have a number of slides with me to illustrate many of these defects, so if I have a little more time I'll go quickly through these slides and show you just what some of these defects are. I hope you will then relate these defects to trees you have and will be able to understand tree and log grading a little better as a result.

# CULTURE: PAST, PRESENT, AND FUTURE

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**ABSTRACT.**—Black walnut culture began in the U.S. and Europe soon after colonization. Even so, commercial production of black walnut timber is still restricted primarily to the U.S. and Canada, but interest abroad continues. Present cultural practices are based on many years of experience and recent intensified research. Continuing research and additional experience are needed to improve practices. Research efforts are especially lacking in protection from insects and diseases and in economics.

Thanks to a rapidly growing body of knowledge gained through years of research and experience, we now know with reasonable certainty how to establish and grow high quality black walnut crops. Even so, many specific problems remain to be solved before we can prescribe all the major steps in a technical system for walnut management on a wide range of sites.

Black walnut culture in recorded history began a few years after colonization. Rebmann (1907)<sup>1</sup> places its introduction into Europe about 1629. There are several citations in early European forestry literature of American walnut plantings. A natural hybrid between black walnut and Persian walnut was reported in France more than 150 years ago. There has been a continuing interest in black walnut introduction and culture in Europe for several years, but commercial walnut culture in Europe is usually limited to *Juglans regia*. A large black walnut plantation was recently established for timber production in Australia. Although the species has been planted in other countries for several hundred years, eastern United States and parts of adjacent Canada remain the primary commercial source of black walnut timber.

In North America the value of the wood was recognized soon after settlement. Walnut timber entered early Colonial commerce, and was a popular cabinet wood. I suspect that the earliest conscious cultural practice was to leave walnut trees on land cleared for

pastures. This several-hundred-year-old practice likely developed because someone observed that such trees provided a convenient supply of nuts plus useful shade for livestock without greatly reducing forage production. This same practice is still followed in many parts of the country, and owners now recognize the added value of timber production. Favoring walnut trees in pastures thus has a significant impact on commercial timber and nut supplies. This practice is not to be confused with running cattle in woodlands, which is not recommended in central hardwoods.

When the settlers moved from clearings in heavily wooded areas to the prairies, they hated to give up their walnut trees. So they — maybe at the insistence of the women — took walnuts with them into the eastern prairies. Again, I suggest that the primary reason was for nuts although lumber for furniture and shade for the farmstead made walnut a popular multi-purpose tree beginning about 1850. Farmers who learned to crop the prairies instinctively knew that in order to grow trees on the prairie you must control weeds and grass. Walnut groves became part of the prairie landscape in Illinois, Iowa, and adjacent States. Here is how Mr. D. C. Scofield of Elgin, Illinois, recommended establishing walnut, based on his experience beginning in 1858: "These facts lead to the conclusion that black walnut will succeed on dry, rich soil if cultivation is continued till the trees are able to shade out grass..." (Hough 1877).<sup>2</sup>

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<sup>1</sup> Rebmann. *Transactions of the German Dendrological Society*, 1907. p. 187-209. 1907.

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<sup>2</sup> F. B. Hough. *Report upon forestry. U.S. Dep. Agric.* 650 p. 1877.

There is strong similarity between the foregoing prescription and the planting systems developed during the past few years. The big difference is the use of herbicides, but the basic ingredient is the same: control of weeds and grass. Like the principles of Mendel, the early prescription for establishing the prairie plantations was lost. Emphasis on mass production, cost-cutting methods that prevail even today replaced the know-how developed through early practical experience.

Although initial establishment was good, the low quality of individual trees in walnut groves shows that culture did not extend beyond the establishment period. Excessive grazing, fire, and lack of pruning resulted in poor quality trees that were avoided by the veneer industry until 10 to 15 years ago. Most of the old walnut groves have now been harvested for domestic and foreign consumption even though there have been problems of quality relating mainly to persistent branches. However, the harvest of walnut groves has proved emphatically that black walnut can be grown successfully in pure plantations if agronomic practices are followed.

The basis for the current recommendations for planting and caring for walnut has evolved from many years of research and experience. Research was somewhat sporadic from the 1930's until about 1960. During this period, interest in walnut culture was relatively modest, sustained primarily by programs of the American Walnut Manufacturers Association and a few zealous extension foresters and State foresters. Since 1960 there has been a steady increase in the interest in walnut culture. Unquestionably, this interest coincided with higher prices being offered for quality timber.

Because of the combined efforts of many individuals, industry, and public agencies, we can now prescribe with some certainty how to establish plantations and how to culture immature trees. Better technical information, especially for plantation establishment, has increased interest in walnut. Site evaluation has improved. Seed can be stored for several years and better seedlings are being produced in the nursery. Using large, well balanced seedlings, we can plant by any one of several methods if basic principles are followed. Then with either mechanical or chemical weed control, survival in excess of 80 percent can be expected routinely.

We are beginning to learn how to shape the trees during the first few years after planting, but early

form remains a serious problem. Some guides have been developed for pruning both planted and natural trees for clear wood production. We know something about plantation spacing and mixed plantings. Pole-sized trees in natural stands were found to respond well to release.

Thus, through new knowledge, significant progress has been made to improve field practices during the past 10 years. Interest in special walnut cost-sharing programs for planting, release, and pruning is growing rapidly in many States. Even so, efforts should be redoubled to get greater participation in cost-sharing not only for walnut but for other forestry practices. Walnut stock production in State nurseries has increased four-fold since 1963 and the quality of the seedlings has improved. More important, Cooperative Forest Management foresters are requiring and getting better jobs done under cost-sharing. More and better technical information is available to the forester and the grower. A key factor in the recent improvement in cultural practices surely has been the intensive training efforts being made by various university extension specialists, State organizations, industry, and the Northeastern Area of State and Private Forestry of the Forest Service. More recently the Walnut Council has become a significant factor in promoting the culture of walnut.

Good progress has been made in solving problems in walnut culture, but it does not take the walnut expert long to run out of specific answers. We still must do too much generalizing in a number of specialized areas. Positive evaluations are needed to define the potentials for a wider range of walnut sites, especially on the medium-to-poor sites. A good start has been made on fertilization research; some early results are promising but others are erratic. In some years, many States find it difficult to obtain adequate seed for nursery stock production. The few seed production areas established will produce only a fraction of our total needs. Some refinements are needed in nursery production and seed handling, and all nurserymen are not convinced that larger seedlings are best or that the advantages are worth the added cost. We are not yet able to produce the kind of seedling or develop the conditions needed to get rapid growth the first year after planting. And planters need to be aware that improved plant material may need special treatment when and if it becomes available.

Further refinements are needed for corrective pruning. We do not know how early to start pruning for

clearwood production, and we have not determined for all ages and sizes the optimum amount of crown to remove at one time without reducing growth or quality. The optimum amount of growing space individual trees need at different ages in natural stands or in plantations has not been determined. Industry has expressed concern about the sapwood-heartwood ratio of fast-growing planted trees.

Better information is essential to establish thinning schedules and regulate spacing throughout the life of walnut stands on different sites. Closely related to the subject of spacing is the topic of multiple cropping. A

good start has been made, but yield and quality data are needed for wood, grass, and nuts.

We have a good story to tell about how well black walnut is suited to intensive culture. Many landowners and foresters are convinced that the high prices paid for quality trees is reason enough to plant and tend walnut crops. Unfortunately, essential questions about economics and potentially disastrous pests remain unanswered. It is time to get down to business and develop an operational system on an economic basis. All of the costs and how to reduce them must be considered. And we need to consider all of the benefits — esthetics as well as timber, nut, and grass production.

# SELECTING THE BEST AVAILABLE SOILS

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**ABSTRACT.**—The relationship between observable soil characteristics and black walnut growth is discussed, and a procedure presented for using soil and topographic factors to select and evaluate areas for growing black walnut. Also, the influence of soil characteristics on the need for and extent of various cultural practices is examined.

One of the most important decisions the black walnut grower makes is selecting the area to grow this valuable timber and nut-producing hardwood. Growing a crop of high-value walnut trees is a long-term project that requires investments for planting, weed control, shaping, and pruning. Cultural practices could prove ineffective if the trees do not respond because of unsuitable soil conditions on the site. Or the grower's investment could be lost if the walnuts die. The grower should remember that a few extra minutes spent initially in evaluating the soil may mean the difference between success and failure.

This paper summarizes the soil characteristics that influence walnut growth, tells how to select the best available soils, and explains how soil characteristics influence the use of cultural practices.

## SOIL CHARACTERISTICS INFLUENCING GROWTH

In the proceedings of the 1966 Black Walnut Workshop, Carmean (1966) reviewed the literature pertinent to the soil-site relations of this valuable hardwood. He indicated that there had been few studies of walnut site requirements and that only general estimates of site quality could be made. About all that was known was that better growth occurs on deep, well-drained soils with a medium texture and a loose, permeable subsoil, and that shallow, heavy-textured, or imperfectly drained soils are not suitable for walnut. Attempts to associate

soil chemical properties had not yielded conclusive information relating soil reaction and nutrients to better growth of walnut. Carmean described the height-growth pattern of five black walnut trees growing in 25- to 30-year-old plantations. The initial height growth was generally rapid, even on the poor sites, but the height-growth pattern varied widely after this period.

On the basis of later research, Carmean (1970) reported that the height-growth patterns of walnut are related to certain soil conditions. Losche (1970) found that the internal soil drainage of a site influences walnut height and diameter growth. Growth tended to be greater as the depth to mottling (evidence of restricted internal drainage) increased. Diameter growth was about 2.6 inches greater in 25 years on well-drained soils (30 inches or more to mottling) than on imperfectly drained soils (6 to 30 inches to mottling).

A study of walnut plantations in southern Illinois showed that the presence of a gravel layer was the key soil characteristic affecting growth on narrow floodplains. After 25 years, trees were 17 feet taller and 2.5 inches greater in diameter on deep soils (more than 40 inches to gravel) than on shallow soils (gravel within 40 inches of surface). The faster height growth on deep soils would increase the possibility of harvesting a second 16-foot log or developing a larger crown for nut production. If this diameter-growth pattern continues, the time to produce a merchantable 16-inch log will be reduced from 100 years to about 60 years.

Depth to mottling or gravel effectively limits the rooting zone from which moisture and nutrients must be obtained. Although these studies did not include soils

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<sup>1</sup> The Station's laboratory in Carbondale is maintained in cooperation with Southern Illinois University.

with hardpans, claypans, fragipans, or other root-inhibiting features, walnut growth would likely be reduced on these soils also.

## SELECTING THE BEST AVAILABLE SOILS

A grower's initial concern should be to select from the available areas those best suited for walnut. Research has shown that he will have to make investments for early cultural care in order to get a successful plantation; therefore, he will want to be sure that the proposed area will sustain rapid growth from planting to maturity.

The grower may examine the soils himself or seek the assistance of the local service or extension forester serving his area. In either case, the service forester should be contacted to obtain the latest information on weed control, pruning, and all other aspects of walnut culture.

For the "do-it-yourself" grower, the following topographic and soil characteristics should be looked for and evaluated at each potential area. By selecting the area with the least number of factors that would limit walnut growth, the grower will have selected the best available area on his land.

### A. Topographic Factors:

(1) *Smooth and gently rolling landscapes.* — Site position is not generally a critical factor in these areas. Soil characteristics, such as texture and internal drainage, are most important.

(2) *Strongly rolling and mountainous landscapes.* — Site position and slope aspect, as well as soil characteristics, are very important in site selection. The better planting areas are typically located on the lower north- and east-facing slopes, stream terraces, and floodplains. Steep, south-facing slopes and narrow ridgetops would generally be poor walnut sites.

### B. Soil Characteristics:<sup>2</sup>

(1) *Texture.* — Suitable soils have a sandy loam, loam, or silt loam topsoil texture; the subsoil should have the same texture or a sandy clay loam or clay loam. Soils with coarse sand or gravel layers and bedrock with-

in 2 to 3 feet of surface should be avoided, as should soils with acid, clayey subsoils. Limestone soils with silt loam over clayey subsoil are good planting sites.

(2) *Internal drainage.* — Soils with a uniform brown, yellowish- or reddish-brown color to 3 feet or more are well-drained. Soils with evidence of mottling within 2 feet of the surface should be avoided. Mottling refers to the color pattern of a soil with restricted (slow) internal drainage. A soil with red, yellow, or gray spots (blotches) or a uniform gray color indicates slow internal drainage.

When requested, a State service forester will examine your land with these characteristics in mind, and he will also have some experience with how well walnut grows on the local soils. He will also know how to obtain and interpret soil survey information and have technical guides<sup>3</sup> available to aid in selecting the best available land.

## SOIL CHARACTERISTICS INFLUENCING CULTURAL PRACTICES

The growth response to most cultural practices will be directly or indirectly influenced by soil characteristics. For example, the effectiveness of early weed control treatments using pre-emergence herbicides depends on using the appropriate rate of chemical; this varies with soil texture, reaction (pH), and organic matter content. The rate necessary generally is higher as soil texture becomes finer, as pH increases, and as organic matter content increases. Silvicultural operations such as weeding and thinning indirectly affect the soil moisture and nutrient supply by reserving the soil's limited natural supply for the crop trees, especially on droughty and infertile soils.

Especially during the establishment period of a plantation, the grower will use practices similar to those of a

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<sup>3</sup> For example: "Guide to the Selection of Soil Suitable for Growing Black Walnut in Illinois," by C. K. Losche, W. M. Clark, E. E. Voss, and B. S. Ashley. Special Publication, Northeastern Area, State and Private Forestry, USDA Forest Service, Upper Darby, Pennsylvania. 1972. (Cooperative publication of the Forest Service and Soil Conservation Service.) Similar technical guides are available in all States from local service foresters and Soil Conservation Service personnel.

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<sup>2</sup> Dig a soil pit or use a soil auger and check soil characteristics to at least 3 feet.

row-crop farmer. Like the farmer, the walnut grower has made a substantial investment when establishing a plantation; therefore, he must protect his investment by selecting the best available soil and by planning his cultural practices with regard to the soil characteristics of the area selected.

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# ESTABLISHMENT AND EARLY CULTURE OF PLANTATIONS

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and

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**ABSTRACT.**—Presented is a summary of information needed to establish and care for black walnut plantations. Subjects discussed include: how to choose a planting site, spacing, seedling selection and care, when and how to plant seedlings or seed, benefits from interplanted species, the need for and how to control weeds, when and how to prune to promote apical dominance, and clear stem pruning.

## INTRODUCTION

Since the 1966 Walnut Workshop much interest has been generated in growing black walnut. News of the high prices paid for some walnut trees has probably created more interest than any other factor. People are demonstrating increased interest in walnut by planting trees. In 1971 about four times as many walnut seedlings were planted as in 1963. The increased interest in walnut planting will likely continue. Our research and experience in establishing successful walnut plantations during the past several years is summarized here and may prove helpful to new growers.

## SITE SELECTION

Site selection is the most important step in establishing a walnut plantation. Walnut plantations should never be established without a knowledge of the soils. Soils are difficult to understand, so an expert should be consulted to determine soil capabilities for good tree growth.

For continued good growth walnut trees need deep, well-drained soils. Although the minimum soil depth recommended for growing black walnut is from 30 to 40 inches, trees will penetrate a much greater depth of available soil. One 9-year-old walnut tree had an excavated tap root about 7½ feet long and lateral roots 8

feet long (fig. 1). Often potential sites appear good on the surface but are undesirable because of various root restrictions. Fragipans, high water tables, and shallow soils — either to bedrock or to gravel (especially fields along stream bottoms) — are examples of barriers that restrict root growth.

Brushy areas and cleared forest sites can be excellent for growing walnut. However, herbicide treatment of all stumps is imperative to prevent sprouting.<sup>2</sup> Pasture areas, and fields previously under cultivation, are good walnut planting sites, too, if the soils are deep, well-drained, and not too badly degraded.

## SPACING

Spacing should be wide enough to accommodate the equipment that will be used in the plantation. Most farm equipment can easily move between rows planted on an 11- by 11-foot spacing and will cause little damage to the trees if the operator is careful. Checked rows permit cultivating and mowing in four directions (fig. 2). Also, in checked plantations a lone tractor operator, by using boom sprayers, can simultaneously spot spray herbicide at the base of individual trees in two rows. In unchecked plantations only one row can be sprayed. Although the initial cost of establishing a checked plantation is high because of the time required for layout, a large checked plantation may provide tremendous savings in long-term labor costs.

<sup>1</sup> The Station's laboratory in Carbondale is maintained in cooperation with Southern Illinois University.

<sup>2</sup> See page 114.



Figure 1. — *The tap root of this 9-year-old walnut tree is about 7½ feet long and the lateral roots extend more than 8 feet from the tap root.*

## SEEDLING SELECTION AND CARE

Only large, vigorous, well-balanced walnut seedlings should be planted. Seedlings ¼-inch or larger in diameter, measure above the root collar, survive better and grow faster than smaller ones and should be used (Williams 1970). Based on results of one study, root fibrosity does not affect either survival or early growth (Williams 1972). Roots may be pruned to 8 to 10 inches. Only the large, vigorous seedlings have been planted in company plantations and survival has been 98 percent.

Seedlings that cannot be planted for 1 or 2 weeks after they are received from the nursery should be heeled-in or placed in cold storage until planted. Walnut seedlings that will be planted in a few days may be left in the bundles if stored in a cool, moist, shady place.

## PLANTING METHODS

Dormant seedlings should be planted in the spring anytime after the frost is out of the ground. Spring planting is more successful than fall planting because many fall-planted seedlings will frost heave.

Several planting methods are suitable for planting walnut seedlings. The KBC planting bar and a 6-inch post-hole auger, mounted on a chain saw engine, are two good methods (fig. 3). Planting machines can be used, too, but care must be taken to ensure that the seedlings are planted deep enough and straight. All seedlings should be checked after they are planted to make sure they are upright. Slanted trees should be straightened with a spade or planting bar.



Figure 2. — *Walnut rows in Pierson-Hollowell plantings are checked on an 11- by 11-foot spacing to allow cultivation in four directions.*

Regardless of the planting method used, the root collar of the seedlings should be planted 1 or 2 inches below the ground line. The hole or slit should be large enough and deep enough to accommodate the entire root system. Then with the seedling held upright, the soil should be firmly pressed around the roots to eliminate air pockets. Roots of walnut seedlings taken to the field should be kept in wet peat moss or some other suitable material to prevent the roots from drying.

Although planting walnut seedlings has proven to be the best method for establishing plantations, seed (nuts) can be planted, too. However, because rodents, especially squirrels, pilfer the seed, direct seeding has been very disappointing. Several methods have been tried in order to protect the nuts. Some of the more effective ones have been the tin can method and cones or cylinders constructed from screen wire or hardware cloth. Tin cans should be burned to hasten decomposition. An emergence hole is then punched in the closed end so that the jagged edges of the hole protrudes to the outside. The can is then filled with soil so that the enclosed nut will be planted 1-inch below the emergence hole when the can is placed in the ground, emergence hole up. Cones or cylinders must be buried 2 to 3 inches and

anchored to prevent the rodents from digging under them. Planting nuts could reduce plantation establishment costs tremendously if the problem of rodents could be solved. More research should be done in this area.

Low germination has been another problem confronting direct seeding enthusiasts, but planting germinated nuts could eliminate this problem. In the spring, after fall-collected seed has been in outside or cold room stratification at least 90 days, the seed should be placed in an environment suitable for germination (warm — about 70° F. and moist). Because the nuts should be planted before the radicle becomes long enough to be broken easily, the nuts should be inspected every second or third day to remove germinants. Germinated nuts should be planted immediately but may be held a few days in cold storage before planting.

On a limited basis we have planted container-grown seedlings and tubelings. Survival and growth of container-grown seedlings were excellent but the difficulties in handling and transporting container-grown seedlings would be too difficult for large-scale planting. Our experience with tubelings was disappointing. Neither survival nor growth was improved over bare root seedlings.

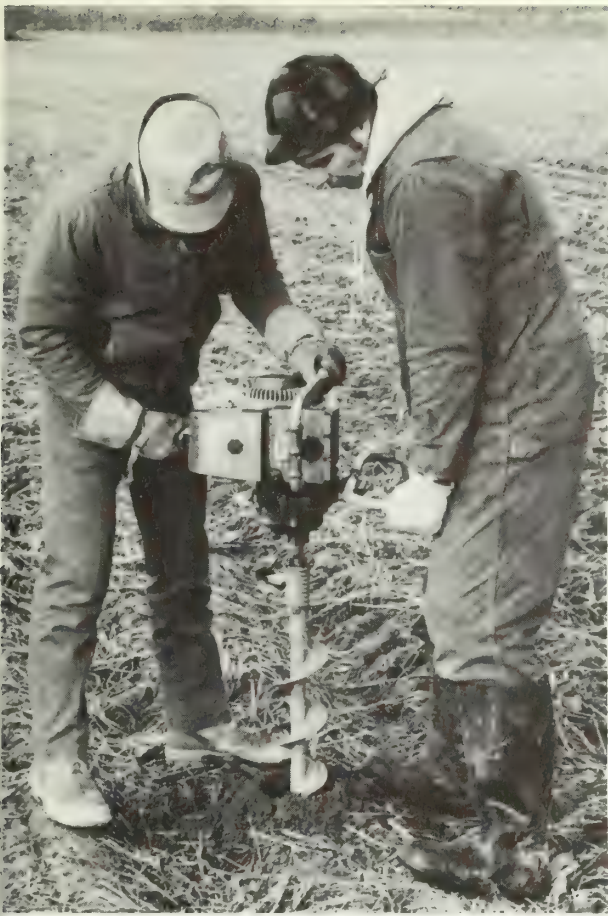


Figure 3. — A 6-inch diameter planting hole being dug with a chain saw post-hole auger.

## INTERPLANTINGS

Several species have been interplanted in studies to: (1) force walnut height growth, (2) hasten natural pruning, (3) provide wind protection, and/or (4) provide nitrogen fixation. Some fast growing species should not be interplanted until the walnut is in its second or third growing season. There should be no danger of the interplanted species interfering with the growth of the walnut. We have interplanted white ash, white pine, autumn olive, black locust, and European alder. All species mentioned will force walnut height growth, cause natural pruning, and provide some wind protection.

The importance of wind protection should not be overlooked. Excessive transpiration rates and mechanical leaf injury were caused by wind movement (Schneider, *et al.* 1968). In Pierson-Hollowell plantations the best growth has occurred on trees located in areas where some wind protection has been provided. In the future,

company plantations that need wind protection will be interplanted before the second or third growing season. More research is needed on wind protection of sapling-size walnut plantations.

To date European alder appears to be the best interplanting species in the Pierson-Hollowell plantations. In addition to wind protection, pruning, and forcing faster height growth, European alder, in association with root nodules, fixes nitrogen in the soil that may be utilized by the walnut. Where European alder has been interplanted in our plantations, growth of the walnut has been excellent. After 5 years the European alder is slightly taller than the walnut (fig. 4). If the walnut cannot compete, the European alder should be topped but not removed so it can continue to fix nitrogen and provide natural pruning. We believe that interplanted trees will greatly reduce pruning costs.

## WEED CONTROL

Weeds and grasses must be controlled around each walnut seedling the first few years to increase survival and promote faster growth. Weed control is second in importance only to site selection in establishing walnut plantations. In addition to better survival and faster growth, weed control reduces rodent damage by eliminating their cover. Herbicides control weeds and grasses best but competing vegetation can be controlled by cultivation, too. However, seedlings can be damaged when equipment is used too close to the seedling. Cultivation is very effective between the rows to supplement spot or strip herbicide treatment around the seedlings (fig. 2). However, if all vegetation is controlled either by herbicides, mechanical cultivation, or a combination of the two, erosion becomes a serious problem, especially on sloping lands. An excellent combination treatment is to use herbicides around the seedlings and mow between the rows. Unless the weeds are tall and very dense, mowing may not be necessary. However, rabbits cut off small seedlings and field mice and groundhogs damage seedlings by chewing on the bark. These animal problems can be reduced or eliminated by cultivating or mowing between the rows to eliminate cover.

Strip spraying along the rows is an effective means of weed control. Strip spraying may be used in interplantings where spacing within the rows is too close to permit cross mowing or cultivating.

## CORRECTIVE PRUNING

Corrective pruning during the first few years of the walnut plantation is a necessary expense. *Before* plant-



Figure 4. — A 5-year-old walnut tree (center foreground) trained and nourished by 4-year-old interplanted European alder (right foreground) which is slightly taller than the walnut.

ing it may be necessary to prune broken or damaged stems. Stems damaged or broken *during* planting should be pruned immediately. Either time, all damaged stem should be cut off above a live bud. Removing this damaged stem can reduce the incidence of slanted or multiple stems.

Severe spring frost may kill part or all of the new growth. Frost damage in new plantations necessitates a pruning expense. Frost damage will continue to be a

problem unless a way is found to prevent it, or unless frost-hardy seedlings are produced through genetic selection. How to prevent frost damage is another major problem on which we should focus more research.

A new, very effective technique for correcting forked or multiple stemmed trees is "tape pruning" (Bey 1973). The technique requires that trees be pruned in the spring just before growth starts. Timing is important because the tape deteriorates in 2 to 3 months and must

be in place during the rapid growth period. Two or more stems of a tree with multiple leaders should be drawn together to straighten the selected leader. Wrap the area where the stems cross 3 to 6 times with 1-inch masking tape. Then clip the tips of all but the selected leader above the tape. With few exceptions, trials of this method in 1971 and 1972 resulted in single, straight stems.

Black walnut has the unique ability to sprout after being damaged by frost, chemicals, machinery, wind, or insects. Normally trees will sprout within 2 or 3 weeks if damaged during the growing season. Trees should be correctively pruned as soon as it is possible to choose the best stem. If several new shoots appear, all except the largest, most upright should be removed.

During the summer of 1970, the periodical cicada or 17-year locust did extensive damage to 1- to 2-year-old walnut plantations in Indiana. In a planting near Richmond, Indiana, all damaged seedlings were coppiced (stem cut 1 to 2 inches above the ground) before the 1971 growing season. Most of the coppiced seedlings sprouted and looked very healthy during the 1971 growing season. Coppicing is an effective method for correcting extensive damage to small walnut trees (less than 3 inches in diameter). Because of potential heart rot, coppicing should be used only as a last resort on trees larger than 3 inches.

Dieback sometimes occurs in 1-year-old plantations. This problem is probably due to poor transplanting stock or improper care of the seedlings before planting. Do not become impatient and replace these apparently dead seedlings until it is obvious that they are dead. The root system of many may still be alive and a new sprout will develop. If dieback occurs, a firm upward pull on the stem will determine if the root system is dead or alive. A dead root system will slip out of the ground while a live root system will hold.

## CLEAR STEM PRUNING

To produce a stem free of knots it is necessary to remove a few lower branches periodically as the walnut tree increases in height until 17 feet of bole are limb free. An adequate crown is needed to produce good growth so don't remove lower branches too fast. At least half the total tree height should be in live crown. Removing too many limbs from young trees could concentrate too much growth at the terminal and cause the tree to bend over under its own weight.

Equipment striking side branches and breaking or tearing them from the stem is a serious problem. A pruning technique has been used in Pierson-Hollowell

plantings that has reduced the damage caused by equipment to seedlings and saplings. Lower branches are sheared during the dormant season, leaving 8- to 10-inch stubs. Shearing has several advantages: (1) There are no branches to damage in *early* spring when important cultural practices such as spraying, cultivation, and mowing are performed. (2) There is only a slight increase in the diameter of the stub left on the stem (a normal branch will about double in diameter). (3) Shearing forces height growth in early spring, but later, lateral buds form new branches on the stubs bringing the tree into balance. (4) If equipment strikes the limb, only the new growth (which originates on the stub) will be torn off, leaving the main stem intact.

## FERTILIZING PLANTATIONS

Walnut plantations established on the proper soils will receive sufficient nutrients for good growth. Indiscriminate use of fertilizers may depress seedling growth by stimulating competing weed growth.

Fertilizer tablets (20-10-5) were placed in 1,000 planting holes in a 1968 company plantation. Five years after planting the fertilized seedlings were not growing any faster than the unfertilized seedlings. In 1970 tablets were placed in 1,400 more planting holes. The first growing season the leaves were deeper green than the unfertilized seedlings, but there was no difference in diameter or height growth.

## CONCLUSIONS

Walnut has a high potential value and appears to be a desirable investment. But unless the necessary weed control and corrective pruning are done when needed, walnut growth would be slow and the crooked, limby trees would be of little monetary value.

Before planting walnut the land manager should provide for the weed control necessary for fast, early growth and the corrective pruning and clear stem pruning needed to produce valuable lumber and veneer logs.

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# WEED CONTROL

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**ABSTRACT.**—Weeds are unwanted plants that seriously compete with young black walnut for essential growth factors — space, light, moisture, and nutrients. Weed control is very important in plantations to assure successful establishment and early growth of walnut. Mechanical or chemical methods are feasible for weed control; but chemical control with pre- or postemergence herbicides is normally more effective and economical. Herbicides can be applied broadcast over entire areas or restricted to strips or spots adjacent to planted trees. Users of herbicides should be familiar with herbicide regulations and strictly adhere to precautions and directions listed on the label.

Weed control is important in the early years of black walnut (*Juglans nigra* L.) establishment and growth. Weed competition is especially critical in walnut plantations, because they are usually established on good sites in full sunlight — ideal conditions for vigorous growth of many types of weeds. Under these conditions, weed species may compete with black walnut for space, light, moisture, and nutrients. These environmental factors are essential for optimum growth and development of black walnut, at least in its early years.

Weed competition can result in reduced growth and vigor or mortality of young trees. It may cause physical deformities that reduce walnut merchantability and quality. Weeds also can provide habitat for rodents that may girdle or even cut off the planted seedlings (Byrnes 1966). Monetary losses attributable to lack of weed control in tree culture have not been determined. However, in agricultural production direct losses due to weeds have been estimated to exceed \$5 billion annually (U.S. Department of Agriculture 1965).

Weeds simply are plants growing where they are not wanted. For our purposes, they can be classified into two broad groups: (1) *woody species*, including trees, shrubs, and vines and (2) *herbaceous species*, including grasses, sedges, and broadleaved plants. It is important to assess the kind of weed problem existing on a given area and even to recognize individual weed species. The weed species present, their stage of growth, and existing soil characteristics need to be identified in order to apply the most effective, efficient, and economical weed control methods.

## WEED CONTROL METHODS

Weed control in walnut culture may be needed prior to or after plantations are established, or in natural stands. The need for site preparation will depend on the competition present. Problem weeds present may be controlled by mechanical or chemical methods as described at the first walnut workshop (Byrnes 1966).

Previously recommended chemical methods are still effective in black walnut culture. However, some herbicides have been restricted for certain uses by Federal and State agencies. Users of these materials should familiarize themselves with their local and State regulations by contacting county agricultural agents, extension specialists, and service foresters. Also, always read the label, heed precautions, and follow directions when using an herbicide (see page 114).

Two major herbicides that have been used for weed control in black walnut production are now under new regulations. These are 2,4,5-T and amitrole. Both are prohibited by the Environmental Protection Agency for use on cropland or food crops, but their use is not affected for other purposes, except around homes and waters. These two chemicals are not presently registered for black walnut, because black walnut nuts are considered a food crop. Future regulations of these chemicals, especially 2,4,5-T, are pending the outcome of public hearings by the Environmental Protection Agency. Implementation of new legislation under the Federal Environmental Pesticide Control Act of 1972 (U.S. Congress 1972) undoubtedly will result in close regulation of some herbicides at the Federal and State level; and further, it is probable that some herbicides will be restricted to use by certified applicators. With these developments, we are truly in the era of prescription weed control.

## Plantation Weed Control

Weed control in young walnut plantations is most important. Heavy sod and/or dense stands of herbaceous weeds seriously interfere with seedling establishment. Mechanical, chemical, or combined methods can be used to achieve the desired control in preplanting or postplanting treatments. Though complete eradication of weeds may be desirable, it is not always practical or feasible.

### Mechanical Control

Cultivation can be used to destroy existing vegetation and prepare the site for planting. After the plantation is established, cultivation, mowing, or mulching may be used. Mechanical control involves more work and is usually more expensive than chemical control. However, if the landowner has equipment and labor available, mechanical methods may be the best alternative.

Mowing controls weed competition for space and light. It may favor changes in species composition to

low-growing biennial and perennial weeds that compete with planted trees for moisture and nutrient elements. Weeds should be mowed as close to the trees as possible. Repeated followup treatments are needed during the growing season. On moist, fertile sites, mowing may be an entirely satisfactory weed control method, if done frequently.

Cultivation is the most practical mechanical means of controlling weeds. A rotary tiller or disc harrow is customarily used. Cultivation should be repeated as often as necessary to keep weeds from getting over 6 inches tall. Care should be exercised to avoid damage to shallow feeder roots of walnut trees. When using cultivation or mowing equipment in the plantation, special care must be taken to avoid injuries to walnut stems that could result in physical deformities or provide entry sites for insects and disease.

Mulching is practical only in small plantings. A 4-foot square of black plastic film can be split, placed around a tree, and anchored to the ground. However, plastic will sometimes cause heat-girdling damage and may provide cover for mice that could damage roots and lower stems. Sawdust and wood chips can also be used as mulch, but existing vegetation should be removed before mulch is applied.

## Chemical Methods

Two general types of herbicides are effective for controlling grasses and broadleaf weeds. These are (1) pre-emergence, soil-applied chemicals, which are applied from late fall to early spring on unfrozen soil before weeds emerge and (2) postemergence chemicals, which are applied to the foliage of established weeds.

Pre-emergence herbicides are not very effective on established weeds. If advanced weed growth is already present on the planting site, application of a post-emergence herbicide is advisable. Where herbicide application is delayed until spring or early summer, a combination of postemergence and pre-emergence herbicides can be used to kill established weeds and provide residual control of germinating weeds. All pre-emergence herbicides require rainfall or light tillage to incorporate the chemical into the soil, a good reason for treatment a week or so in advance of expected weed emergence. In established plantations, postemergence herbicides *must be used as directed sprays* to avoid damage to the planted trees.

Here are some herbicides for grass and broadleaf herbaceous weed control that we have used experimentally. Some of them are not registered for walnut:

1. *Simazine*: Simazine is a pre-emergence, soil-applied herbicide. It is absorbed by plant roots and translocated to the leaves, where it exerts its toxic effect. Black walnut has a fairly high tolerance for this chemical (Wichman and Byrnes 1971). Simazine normally remains in the upper soil surface due to absorption by clay and organic matter. At recommended rates, it effectively controls most newly germinated grasses and herbs for one growing season. It can be applied in late fall or early spring. Available formulations are 80 percent wettable powder (80W) and 4 percent granular (4G). The granular formulation is more costly for the same degree of weed control. Rates of application for tree species are listed on the label or may be obtained from county agricultural agents and extension specialists, since the rates suitable for good control in cornfields are usually adequate for control around walnut trees. General application rates are 2 to 4 pounds active ingredient per acre in a water carrier. If necessary, simazine can be sprayed over the tops of dormant walnut trees.

2. *Atrazine*: Atrazine is a pre-emergence, soil-applied herbicide closely related to simazine, but exhibits some postemergence activity. It may control emerged weeds if sprayed when they are less than 1½ inches tall. It moves deeper into the soil than simazine, making it more effective on deep-germinating weed species such as morning glory. Black walnut possesses some inherent tolerance for this chemical (Wichman and Byrnes 1971), but field tests have given some indication of a lower tolerance than for simazine. Atrazine 80 percent wettable powder is applied in spring at locally recommended rates. The chemical should not be sprayed on the walnut trees.

3. *Simazine + atrazine* in a mixture may be superior to either of these chemicals alone, for more kinds of weeds may be controlled, because atrazine penetrates more deeply into the soil. This combination is not available commercially. However, the sum of active ingredients should not exceed that for the chemicals applied separately.

4. *Amitrole + Simazine*: This mixture of a post- and pre-emergence herbicide was effective in tests on established weeds and also provided residual control of germinating weeds. In postplanting treatments, accidental

spraying of planted trees must be avoided. Various ratios of the two components can be obtained by mixing as desired. However, Amizine,<sup>1</sup> a commercial dry powder formulation containing 15 percent amitrole and 45 percent simazine, is available and is normally applied at 7 pounds in 100 gallons of water per acre treated. Amizine has also been made available recently in liquid form containing 5.1 percent amitrole and 10.2 percent simazine, but application rates for black walnut have not been completely worked out for the product label.

5. *Dalapon*: Dalapon is normally used as a post-emergence grass killer. It effectively controls many perennial and annual grasses. A rate of 10 pounds of the commercial product per 100 gallons of water per acre has been used in research trials. It must not be sprayed directly on walnuts, and should be applied when grass is growing vigorously, but before formation of seed heads.

6. *2,4-D Amine*: This is a postemergence, foliage-applied herbicide that is effective on most broadleaf weeds. It normally is used prior to tree planting where broadleaf perennial weeds are abundant. It can be used as a postplanting treatment to control patches of perennial vines. Recommended rate is 1.5 pounds acid equivalent of an amine salt formulation per acre in a water solution. Effectiveness may be increased by the addition of a spreader-sticker or low-sudsing detergent. *Do not spray on or allow spray drift to get on the walnut trees.*

### *Mechanical-Chemical*

When chemical treatment is limited to strips or spots in the plantation, it may be desirable to control weeds between the treated areas by mechanical means, either mowing or cultivation. This practice may further reduce competition for soil moisture and may prevent vines from spreading into treated areas. Chemical control in combination with mowing can effectively remove weeds adjacent to the trees and also minimize the erosion hazard on sloping land. If cultivation is used on intervening areas, it should be restricted to land that is not subject to serious erosion; however, cultivation may not have an economic advantage over total chemical control in this situation.

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<sup>1</sup>The identification and description of commercial products in this publication are solely for information purposes. Endorsement of any commercial product by the Department of Agriculture is not intended and must not be inferred.

## Herbicide Application

Methods of applying these chemicals will vary depending on size of area to be treated, terrain, equipment available, type of herbicide to be used, and size of walnut trees. Pre-emergence herbicides can be broadcast over the entire area, or applied in strips or spots. Broadcast applications are the most expensive in terms of chemical cost, whereas spot treatments are the cheapest and the most versatile. Broadcast sprays should not be used on sloping land as they increase the chance of erosion.

For strip spraying, the strips should be about as wide as the trees are tall, but not less than 4 feet. For spot control, the diameter of treated circles should be about equal to the height of the tree but never less than 4 feet (Krajicek and Phares 1971).

Equipment for applying chemicals ranges from boom sprayers suitable for treating large areas of smooth level land to backpack sprayers for smaller areas and on irregular terrain. Some way of continuously agitating the solution is necessary for some herbicides. Granular formulations can be applied with specially designed mechanical spreaders, hand-operated granule spreaders, or by hand.

Boom sprayers must be calibrated so that rates can be applied accurately. The major factors to consider in proper calibration are sprayer pressure, tractor speed, and nozzle height, spacing, and type. Instructions for calibration are usually available from county agricultural agents, extension specialists, or farm supply stores.

When applying herbicides with a backpack sprayer, it is useful to calibrate for small areas, since this type of sprayer is generally used for spot or strip treatments. Assuming 100 gallons of water will be used with 5 pounds of the chemical formulation per treated acre, 10 gallons containing  $\frac{1}{2}$  pound (8 ounces) of chemical would be adequate for  $\frac{1}{10}$  acre (4,356 square feet). For strip spraying of 4-, 6-, or 8-foot widths, 10 gallons of solution should cover 1,090, 725, or 545 lineal feet, respectively. For spot spraying, the 10 gallons of solution will treat the following numbers of trees (Krajicek and Phares 1971):

Tree height	Diameter of spot	Trees treated
(Feet)	(Feet)	(Number)
4	4	350
6	6	155
8	8	90

For hand applications of granular simazine to circular plots around trees, the only tools needed are a pail and a measuring spoon. The required volume of granules is uniformly distributed over the circular plot by hand. Granular simazine should be applied in fall or very early spring because rainfall is required to carry the chemical into the soil.

## Continuing Weed Control

The number of years after plantation establishment that weed control measures should be continued will depend on site factors, plantation objectives, and economic considerations. In plantations managed primarily for nuts, weed control may be desirable for as long as the trees are in production. In plantings managed for timber, results to date show that weed control should be continued for at least 2 to 3 years (Krajicek and Williams 1971). From the standpoint of improved growth, weed control will likely benefit trees until competition among trees becomes a controlling factor of growth. The length of time required for black walnut to dominate a site will depend on such factors as available moisture and nutrient elements.

The type of weed control practiced may change with time. When the planted trees are well above the tallest weeds, complete control becomes less important. However, control of vines such as wild grape, wild hops, climbing buckwheat, and morning glory must be continued until the plantation canopy is dense enough to suppress the growth of these plants.

## WALNUT RESPONSE TO WEED CONTROL — FIELD TRIALS

The beneficial effects of weed control on black walnut growth are evident in results of the following field experiments conducted by Purdue University and the North Central Forest Experiment Station.

### Bottomland Sites — Purdue University

At Purdue University, two studies of walnut growth response to weed control on bottomland sandy loam to loam sites were initiated in 1963 and 1965. In both studies, 2-year-old seedlings were planted at a 10- by 10-foot spacing in a randomized complete block design

with three replicates of the following weed control treatments: (1) none (no weed control), (2) mechanical (cultivation with rotary tiller), and (3) chemical (Amizine at 7 lb./acre). In the mechanical treatments, plots were cultivated three times per season for 3 years after planting in both studies. In the chemical treatments, Amizine was applied once each spring for 3 years after planting. In the 1963 study applications were restricted to milacre plots (6.6 feet square) around each tree. In the 1965 study the entire treatment areas were sprayed. Weed control treatments were discontinued after the third year, but survival and growth measurements have been made annually.

### Survival and Growth — 1963 Test

Black walnut survival after 10 years was excellent, ranging from 85 percent on mechanically treated plots to 95 percent on chemically treated plots (table 1). Average height and diameter were best on the plots receiving total area cultivation and somewhat less on the chemically treated plots (table 1). Although areas with no weed control had 88 percent survival, tree growth was significantly lower than on areas with weed control. Growth response occurred in the second year after planting for trees receiving weed control, but was delayed until the fourth year for trees with no weed control (fig. 1). Although the rate of tree growth on the "no control" treatment was about equal to that on the treated areas in the past 7 years, total growth has been consistently less.

### Survival and Growth — 1965 Test

Walnut survival after 8 years in the 1965 study was 89 percent with no weed control, 88 percent with chemical control, and 79 percent with mechanical control (table 2). In contrast to the 1963 study, average height and diameter were greater for trees on chemically treated plots than for trees on cultivated plots (table 2). Trees with no weed control grew little during the first 4 years after planting, and their average height in fall 1972 was considerably less than trees on plots where weed competition had been eliminated during the establishment period (fig. 2). It is interesting to note in both studies that black walnut survival was good with no weed control and that these trees ultimately began a respectable growth rate. However, it is not likely that they will catch up with trees that had early release from weed competition.

Table 1. — Average survival, height, and d.b.h. of black walnut 10 growing seasons after planting<sup>1</sup>

Weed treatment	Survival	Height	D.b.h.
	Percent	Feet	Inches
None	88	10.1	1.4
Chemical <sup>2/</sup>	95	14.5	2.2
Mechanical <sup>3/</sup>	85	16.5	2.6

<sup>1/</sup>Two-year-old seedlings planted in May 1963.

<sup>2/</sup>Amizine at 7 lbs./A. applied to mil-acre plots around each tree in 1963, 1964, and 1965.

<sup>3/</sup>Cultivation of total area with rotary tiller three times per season in 1963, 1964, and 1965.

### Planting on Cleared Forest Sites — Kaskaskia Experimental Forest

In the future it will become increasingly necessary to plant black walnut on sites already forested with less desirable species. In Hardin County, Illinois, two small coves were cleared and planted to black walnut.

Treatments were (1) complete control of competing vegetation, (2) control of herbaceous vegetation only, (3) control of woody vegetation only, and (4) competition not controlled. For each of the first three treatments, annual, biennial, and triennial control was tested.

After five growing seasons, survival was excellent for all treatments, ranging from 94 to 100 percent. Average height (almost 11 feet) was best for annual complete control. Biennial and triennial complete control, and annual and biennial control of only herbaceous vegetation gave heights almost as good, however. Control of woody vegetation but leaving herbaceous was no better than the check, where average height was only about 4 feet.

### Weed Control (Spot Size and Site Preparation), Indiana and Illinois

The use of spot weed control instead of broadcast treatments is gaining interest. Reduced erosion and pollution and lower costs are the main advantages. But the size of spots needed at various stages of tree development, and whether or not soil preparation is needed prior to initial chemical application are important considerations.

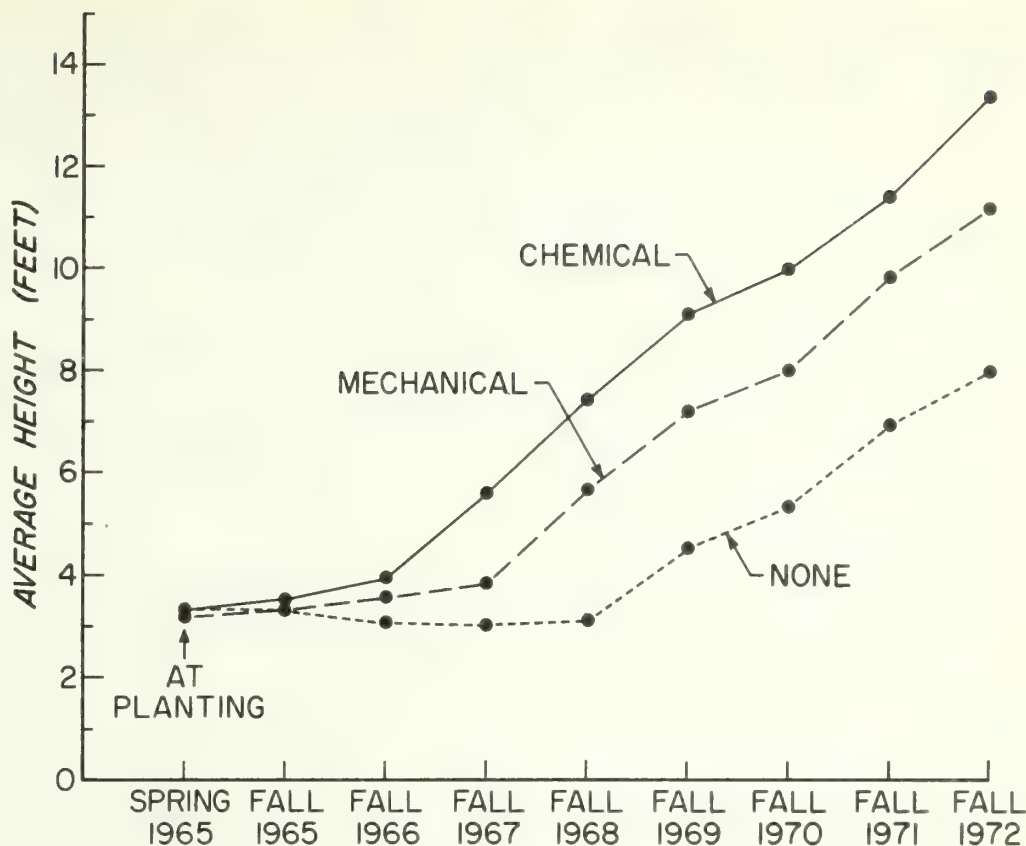


Figure 1. — Average height of black walnut trees during 10 growing seasons by weed treatment — none, mechanical (cultivation over entire area in 1963, 1964, and 1965), and chemical (Amizine at 7 lbs./acre on milacre plots in 1963, 1964, and 1965).

Table 2. — Average survival, height, and d.b.h. of black walnut eight growing seasons after planting<sup>1</sup>

Weed treatment	Survival : Percent	Height : Feet	D.b.h. : Inches
None	89	8.0	0.9
Chemical <sup>2/</sup>	88	13.4	2.0
Mechanical <sup>3/</sup>	79	11.2	1.5

<sup>1</sup>Two-year-old seedlings planted in April 1965.

<sup>2</sup>Amizine at 7 lbs./A. over entire treatment area in 1965, 1966, and 1967.

<sup>3</sup>Cultivation of total area with rotary tiller three times per season in 1965, 1966, and 1967.

The study was established on old-field sites on a bottomland area in south-central Indiana, an upland area in southern Illinois, and a bottomland site in southern Illinois. Both soil preparation and no preparation were tested on all areas. One-year-old black walnut seedlings and germinating nuts were used. Chemical weed control was applied after planting and sowing on circular spots 2, 4, 6, and 8 feet in diameter. On other areas, no weed control was used.

After two growing seasons, few differences in growth and survival are evident. However, it appears that a treated spot at least 4 feet in diameter is desirable. The most significant finding to date is that soil preparation prior to planting had no advantage over no preparation.

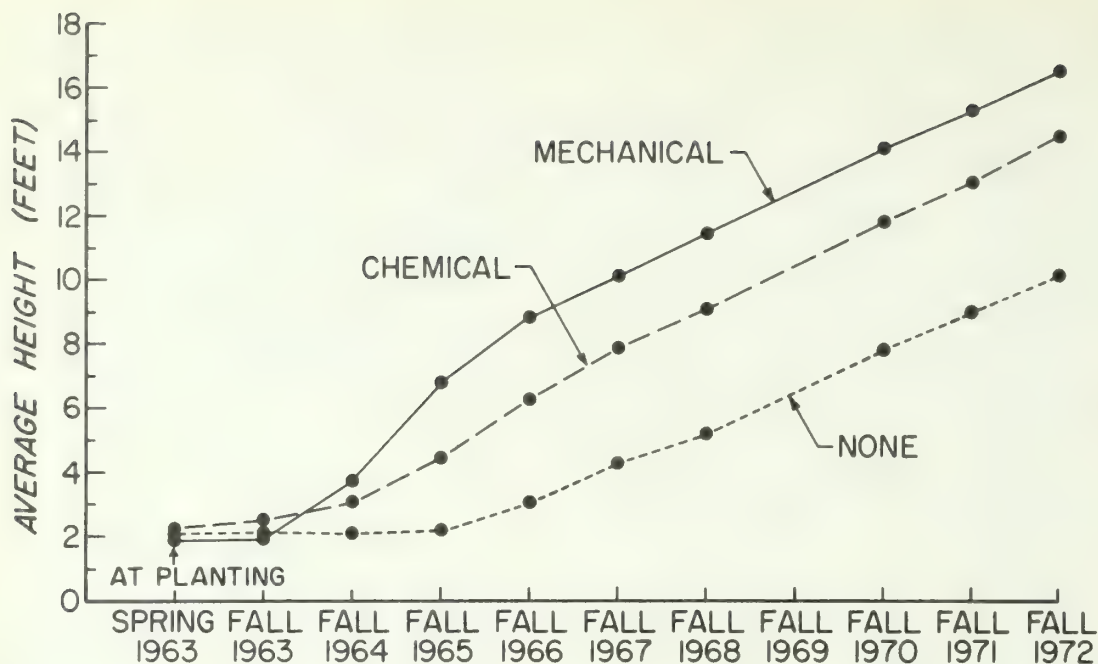


Figure 2. — Average height of black walnut trees during eight growing seasons by weed treatment — none, mechanical (cultivation over entire area in 1965, 1966, and 1967), and chemical (Amizine at 7 lbs./acre over entire area in 1965, 1966, and 1967).

This not only has economic implications but also indicates that areas not readily accessible to soil preparation equipment can be successfully planted.

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# MANAGING IMMATURE TREES FOR MORE HIGH-QUALITY LOGS AND RELATED PRODUCTS

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**ABSTRACT.**—A general review of some of the basic cultural practices in managing immature black walnut trees is presented. It is proposed that potential crop trees be selected as early in the rotation as possible and cultured on an individual tree basis. Early release and thinning are also recommended for maintaining rapid growth. Study results show that pole-sized and small sawtimber-sized walnut trees also grow faster if released and thinned, but older sawtimber-sized trees show little or no response. Tentative stocking and spacing levels for maintaining good growth and good nut production are presented. Corrective pruning and clear-stem pruning are necessary at appropriate times during the rotation to produce straight stems and high-quality wood. Research in progress indicates that fertilization also may be feasible for maintaining good growth.

Good walnut management must begin early in the life of a stand and continue through to final harvest to produce high yields and high-value products on short rotations. Too many walnut growers tend to ignore important management practices after a planting is established, or fail to recognize the advantages of managing naturally established trees. Much can be done with immature walnut trees to promote rapid growth of high-quality wood. Research and experience suggest that with proper care these immature trees can produce good seed crops in 10 to 12 years, 16-inch saw logs in 30 to 35 years, and 20-inch veneer logs in 40 to 50 years from the time of planting on good sites. And by applying some of these same practices to established trees, it is not unreasonable to expect that growth and quality can be more than doubled in only a few years. Without intensive management, growth and yield of immature trees will be lower and rotations longer.

Several basic cultural practices have widespread applicability to management of natural and planted walnut stands for a number of product objectives. Most landowners are primarily interested in growing walnut for high-value timber, but an increasing number are giving more attention to nut production and other aspects of walnut culture. Fortunately, the cultural practices currently recommended for growing high-quality timber generally do not conflict with those recommended for other product objectives. For example, good manage-

ment of black walnut for high-quality timber also generally results in greater nut production. In this paper I will review some of these basic cultural practices and point out where new information has called for changes in emphasis or techniques.

## SELECT POTENTIAL CROP TREES EARLY

Because of their high potential value, walnut trees should be managed on an individual basis, regardless of whether they are in plantations or in natural stands. Therefore, one of the first important tasks for the walnut grower is to select the best trees on which to concentrate wood production or improve nut production. The sooner these potential crop trees can be selected and favored with cultural treatments, the greater the total growth or yield and improvement in quality.

Generally there are fewer good potential crop trees in natural walnut stands than in plantations. Naturally established walnut trees are scattered and vary greatly in age, size, and form. In such cases, the grower must try to do what he can to improve growth and form of the trees available. In the denser stands, and in plantations, it is not practical to try to grow every tree to maturity; so the best trees should be selected at appropriate spacings and managed to improve their form and growth. From the economic viewpoint, it probably is more profitable to work with naturally established trees than to establish new plantations. Growers have minimal investments in the establishment of these trees, and the costs

<sup>1</sup> The Station's laboratory at Carbondale is maintained in cooperation with Southern Illinois University.

of cultural practices to speed up growth and improve quality do not have to be carried too long before the investments can be recovered.

Early growth characteristics often provide a good clue to future development. Therefore, potential crop trees can be selected in relatively young stands. Trees that are forked, have excessively large branches, or are defective for any other reason should not be selected as potential crop trees. Tall, clean-boled trees produce the best veneer logs, so straightness and cleanness of the bole are the best indicators of potential quality regardless of the age at which crop trees are selected. In older stands, the size of the crown and its relative position in the main canopy are good indicators of growth potential. When a choice is possible, dominant and codominant trees should be favored over intermediate and overtopped trees. Select the fastest growing trees as crop trees, using external characteristics such as bark pattern to evaluate current growth rate. The reddish-brown inner bark will be visible in the bark fissures on fast-growing trees. Slow-growing walnut trees tend to have flat, platy bark. Evidence of good nut production in previous years also may be helpful, especially if increased nut production is a major product objective. Trees that have fencing or signs nailed to them are poor candidates for veneer-log crop trees.

## RELEASE AND THIN CROWDED TREES

Selected crop trees should have adequate growing space throughout most of the rotation to maintain rapid growth. If immature trees are crowded or overtopped, crown development and hence the potential for future growth will be seriously restricted. Early and frequent weeding will help keep the crowns above the competition and free to grow. Good site preparation during plantation establishment, especially on brushy fields or forested sites, will reduce the need for early weedings; however, some followup release is almost always needed to keep the walnut trees from being overtopped. Early release is best accomplished by cutting off competing brush and saplings during the dormant season and spraying the stumps with herbicides. Larger trees can be girdled or injected with herbicides. All vines should be removed from young crop trees because they can kill the branches and restrict crown development. Treating stumps of cut vines with herbicides will prevent resprouting.

The first thinning will probably not be needed until the trees reach sapling size (2 to 4 inches d.b.h.), but

if the trees are growing in dense patches, an earlier thinning may be justified. Thinnings should be made every 8 to 10 years to remove slow-growing and poorly formed trees and provide more growing space to the better crop trees (fig. 1). Enough trees should be removed each time to allow the trees to grow about 4 inches in diameter before the crowns become too crowded and another thinning is needed. On most sites, this will mean that tree crowns should be 8 to 10 feet apart after each thinning.



Figure 1. — *This small sawtimber-sized walnut tree has had adequate growing space for several years. Consequently, it has produced a larger vigorous crown, and has good potential for high-value veneer log and nut production.*

The number of crop trees to leave per acre after each thinning, or the amount of growing space to provide each tree, varies with site quality, tree age or size, and product objective. Recommended stocking levels and spacing for high-quality veneer logs and good nut production on good sites are given in table 1. They are based on growing-space requirements of individual trees as determined in previous studies (Krajicek 1966), and on measurements of growth of individual trees in several spacing studies in progress. When nut production is a major product objective, fewer trees per acre should be grown to assure maximum crown development. If the crop trees are grown at the recommended stocking levels, only two or three noncommercial thinnings will be needed before some of the trees will be large enough to sell.

Growth can generally be stimulated by release and thinning even if these treatments are delayed several years, as observed in a number of 25- to 60-year-old walnut stands in southern Illinois and Indiana (table 2). The crop trees ranged from small poles to small saw-timber-sized trees and were growing on a wide range of site conditions. In each stand some of the crop trees were released, and some were not. After 5 years, many of the released trees were growing more than twice as fast as the unreleased trees. Growth response was closely correlated with increase in crown area.

In a similar study with 33-year-old pole-sized black walnuts on strip-mined soils in Kansas, low thinning and single-tree release were employed; diameter growth more than tripled after 2 years (Geyer and Naughton 1971). A strong correlation was found between the amount of crown growing space provided each tree and its diameter growth. Thus, thinning and release treatments must provide room for crown expansion if growth is to be increased.

If the crop trees are released and thinned adequately, growth should be stimulated for several years. An earlier study in Indiana showed that complete crown release doubled the growth of pole-sized black walnut for at least 8 years (Clark 1967, Phares and Williams 1971). A second light release after 8 years resulted in an additional growth increase (fig. 2). The duration of the growth response after release depends on how soon the tree crowns start crowding each other again.

Most pole-sized or larger stands of black walnut generally contain a heavy layer of understory vegetation, especially if they are fairly open and on good sites. This understory vegetation undoubtedly competes with the crop trees for moisture and nutrients, but it may not be practical to control this competition. Removal of understory vegetation from around half of the crop trees in each of the stands studied in southern Illinois and Indi-

Table 1. — *Tentative stocking guidelines for growing high-quality black walnut on good sites*

Average stand d.b.h. (inches)	: Stocking and spacing : : when crowns begin : : to touch <sup>1/</sup> :		Recommended stocking and spacing after thinning or releasing for different product objectives <sup>2/</sup>			
	: Trees : : per acre :		: Veneer logs : : Trees : : per acre :		: Veneer logs and nuts : : Trees : : per acre :	
	: Spacing : : between trees :		: Spacing : : between trees :		: Spacing : : between trees :	
	Number	Feet	Number	Feet	Number	Feet
2	797	7	265	13	225	14
4	380	11	175	16	150	17
6	223	14	125	19	105	20
8	147	17	90	22	80	23
10	104	20	70	25	60	27
12	78	24	55	28	50	30
14	60	27	45	31	40	33
16	48	30	40	33	35	35
18	39	33	35	35	30	38
20	32	37	30	38	25	42
22	27	40	--	--	--	--
24	23	43	--	--	--	--

<sup>1/</sup> Obtained by using the following equation (Krajicek 1966): crown width in feet = 1.993 d.b.h. in inches + 4.873.

<sup>2/</sup> These values are based on the assumption that crop trees will grow 4 inches in diameter before they again need to be thinned or released.

Table 2. — *Effect of crown release on 5-year growth of individual walnut trees in seven stands on a wide range of site conditions*

Stand No.	Site condition	Average age	Crown release treatment	No. of trees	Initial		5-year growth	
					d.b.h.	Initial crown area	D.b.h.	Crown area
		Years			Inches	Square feet	Inches	Square feet
1	Moderately deep silty alluvium over coarse chert deposits	25	Not released	12	5.59	86	0.25	-3
			Released	32	5.86	110	.52	22
2	Ungraded, strip-mine spoil material	28	Not released	5	6.59	107	.62	18
			Released	41	5.71	103	.79	41
3	Ungraded, strip-mine spoil material	28	Not released	12	6.35	118	.63	36
			Released	40	6.92	166	1.22	116
4	Imperfectly drained floodplain soils	25	Not released	13	7.22	151	1.21	23
			Released	64	7.47	159	1.32	86
5	Imperfectly to well-drained floodplain soils	25	Not released	27	8.70	203	.98	39
			Released	67	8.03	192	1.24	88
6	Well-drained upland sandy till soils	40-60+	Not released	11	12.93	303	.76	14
			Released	25	13.93	346	.97	142
7	Imperfectly drained, lower slope	40-60+	Not released	15	13.28	363	.85	165
			Released	29	13.30	406	.94	212

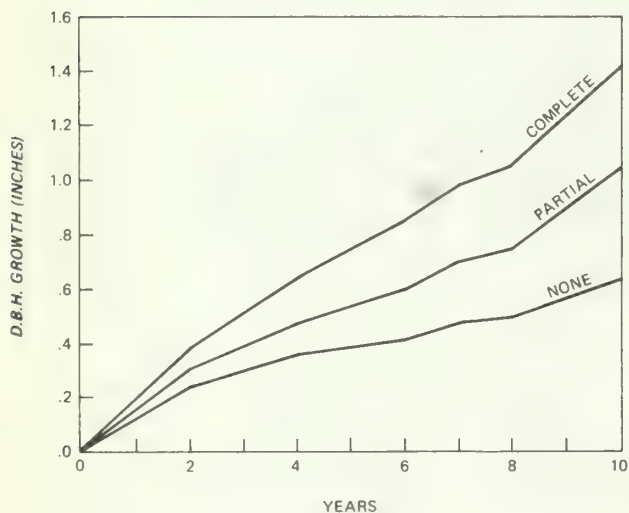


Figure 2. — *Complete crown release stimulated the diameter growth of these pole-sized walnut trees for at least 8 years; a second light release after 8 years further improved growth.*

ana, for example, did not result in any significant growth responses over a 5-year period. Complete understory vegetation control required frequent retreatment (almost annually), which was time-consuming and costly. Therefore, unless the understory vegetation is extremely dense, control is probably not justified on good sites. On poorer sites, where moisture stress is more severe or where nut production is a major product objective, control of understory vegetation may be more beneficial (Holt and Voeller 1971).

Release and thinning of sawtimber-sized trees do not appear to result in much growth improvement. Clark (1967) reported that small sawtimber-sized trees averaging 13 inches in diameter responded less to complete crown release than pole-sized trees averaging only 9 inches in diameter. Nor did the small sawtimber-sized trees in Illinois and Indiana (stands 6 and 7) show much response to crown release (table 2). Apparently the potential for crown expansion is limited on larger trees, and any growth stimulation from release is small and

distributed over a larger bole volume. Thinning can probably be justified in these older stands, however, on the basis of improving nut production. These nuts can be collected and sold, or left to help establish a new stand by natural regeneration. Intermediate thinnings in older stands also make it possible to salvage weaker but merchantable trees that might not survive until final harvest.

## PRUNE TO IMPROVE QUALITY

Selected crop trees should be pruned early in the rotation for the greatest improvement in form and quality. Many of the crooks and forks commonly found in established sapling stands could have been avoided had the seedlings been correctively pruned. Corrective pruning can begin when trees are only 2 to 3 years old, and should continue until a straight, branch-free log 9 feet or longer has been produced (Krajicek and Bey 1969). The more misshapen seedlings should be coppiced in early spring (before June 1) and the new sprouts thinned and tended as new trees. Most naturally established seedlings and saplings also frequently need to be correctively pruned or coppiced to improve their form and growth.

Clear-length pruning can be started when the trees are only sapling size, but it is better to wait until the trees are 3 to 6 inches d.b.h. (fig. 3). Pruning too many branches from the main crown of small trees frequently reduces diameter growth and causes top-heavy crowns, which may break off during strong winds. Clear-length pruning will generally be needed sooner in open stands and widely spaced plantings than in crowded stands where natural pruning has removed many of the lower limbs. By the time a tree is 8 to 10 inches d.b.h. it is marginal for pruning because there will not be enough clear wood produced over the pruning wounds to greatly increase log value when the tree is harvested.

Branches should be cut off nearly flush with the main tree bole, but cutting deep into the branch collar should be avoided. The deeper the cut is made into the branch collar the larger the pruning wound. The pruned branch stub should not exceed  $\frac{1}{2}$  inch in length. The best time to prune is during the late dormant season, and the worst time is midsummer to late summer. The tissue around summer-pruned branch stubs may die back, causing an enlarged pruning wound and slower healing.

It is recommended that no more than a third of the live crown be removed at any one time, even though past research has shown that up to half of the live crown



Figure 3. — *Releasing and pruning immature walnut trees will improve the growth and form and increase their potential value when finally harvested. No more than one-third of the crown should be removed in pruning, and the total live crown ratio should never be reduced to less than half the total tree height. Removing all vines from these trees will help maintain good growth and form.*

can be pruned without reducing growth (Clark and Seidel 1961). Frequent light prunings are recommended over heavy prunings because there is less risk of over-pruning. All pruning should be restricted to the lower half of the bole. How high to prune depends on the product objective and on the cost and difficulty of pruning. When nut production is a major goal, a fairly large crown is needed. Thus on these trees, pruning should be limited to the butt log. The minimum length to prune is 9 feet, but when veneer-log production is a major goal, it may be profitable to prune as high as 25 feet. Pruning above 25 feet is very difficult and expensive.

Some followup pruning may be needed to remove sprouts that have developed around the pruning wounds. These sprouts should be removed as soon as possible to prevent the formation of knots. Epicormic sprouting

is sometimes stimulated by releasing the trees, but it is not recommended that pruning be delayed if the trees are to be released. The sooner the branches are pruned the sooner they will heal over and the more clear wood that will be produced. An extensive release-pruning study in progress shows that if the sprouts on released trees are pruned off a few times, the frequency of re-sprouting can be greatly reduced.

## FERTILIZATION

Fertilizer may be needed on certain sites to obtain maximum yields. Research and experience have demonstrated that pole-sized and larger walnut trees on the less fertile upland sites are most responsive to supplemental fertilization. Fertilizing seedlings and small saplings is not recommended because it only stimulates weed growth and complicates weed control. The older trees seem most responsive to nitrogen fertilization. In one walnut stand in southern Wisconsin, for example, pelleted ammonium nitrate was applied at the rate of 500 pounds of nitrogen per acre around 10 of 20 paired trees on a bottomland site and around 10 of 20 paired trees on an upland site (Anonymous 1968). The trees ranged from 8 to 14 inches d.b.h. and up to 70 feet tall. After 2 years the fertilized trees on the upland site were growing 34 percent faster in diameter than the unfertilized trees. After 4 years the trees were refertilized, and by the end of the seventh growing season, cumulative diameter growth on the upland site was still 37 percent greater for fertilized trees than for unfertilized trees.<sup>2</sup> On the bottomland soils the trees showed little or no response to fertilization, even after reapplication, probably because the soils were already quite fertile.

Much additional research must be completed before fertilization can become a practical management tool for walnut growers. Needed are better methods for diagnosing specific nutrient deficiencies and better infor-

mation on where, when how much, and how often to fertilize for greatest responses. Some tentative guidelines for diagnosing nutrient deficiencies by analyzing the foliage of walnut trees have been proposed (Phares and Finn 1972), but such procedures need more field testing. Even though nitrogen deficiencies are most frequently encountered, elements such as potassium are also needed in larger quantities, especially for nut production, and may be deficient on more sites than commonly thought (Shear 1971). Other specific nutrient needs will undoubtedly be discovered with further research. At least in the foreseeable future walnut growers should concentrate management on the more fertile sites and fertilize only on an experimental basis. Before fertilization is even considered, growers should first make sure the crop trees have been adequately released, thinned, and pruned.

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<sup>2</sup> Personal communication with Robert R. Maeglin, Forest Products Laboratory, Madison, Wisconsin. December 5, 1972.

# TREE CULTURE IN THE SOUTHEAST

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**ABSTRACT.**—Black walnut is scarce in hardwood stands of the Southeast but good potential exists for growing more quality timber. Recent silvicultural knowledge coupled with research findings in other regions make the growing of black walnut practical. Problems, research results, and current recommendations are given for seed collection, nursery practices, site selection and preparation, plantings and cultural practices. Silvicultural goals are stated and the problems needing further research are defined.

The Southeast has a widely recognized reputation as one of the most productive hardwood timber growing regions in the United States. The favorable climate and good soils contribute to sites suitable for more commercial hardwood species than any other region in the United States. Black walnut is one of these species, growing naturally on the best sites from the lower coastal plain to the higher mountains.

During the past century most of the hardwood stands in the Southeast have been cut over at least twice. High-grading has effectively removed the better timber and left the poorer timber as growing stock.

Because of its high value, black walnut has been especially vulnerable to high-grading with the result that it has now become scarce. Most of the black walnut now exists as single trees along stream banks, in pastures and mountain coves, or near old farm buildings. Usually these remaining trees are short-boled, heavy-limbed, and have little commercial value (Brenneman 1971).

The Southeast is not usually considered a region with a high potential for growing significant quantities of quality black walnut timber, but several factors favor growing more black walnut. Because of the numerous deep and well-drained stream bottoms in all physiographic regions, and the deep, fertile coves in the mountains, black walnut occurs from elevations of near sea level to 3,500 feet. Although each site is usually small in acreage, the sites are numerous. Because of the high rainfall, warm temperatures, and long growing season, rotations are short. The wood furniture industry is centered in North Carolina, giving the Southeast an established home market.

Recent studies indicate that the machining properties of fast-growing black walnut are equal or superior to slow-growing trees. Also, the darker heartwood color is advantageous (Englerth 1966), and the sapwood can be treated to closely approach the color of natural heartwood (Brauner and Loos 1968). These findings tend to refute a frequent argument used to discriminate against the fast-growing black walnut typical of the Southeast — that it is unsuitable for veneer.

To date, no appreciable acreage has been planted to black walnut. The reasons for this are a lack of silvicultural knowledge about growing black walnut, and the fact that most of the past plantings have been failures. These two factors have kept many foresters from promoting the planting of black walnut in the Southeast.

Only in the last 5 years has marked emphasis been put on acquiring the silvicultural knowledge required to plant and grow black walnut. Two State forestry agencies, the North Carolina Forest Service and the Virginia Division of Forestry, have experimental programs emphasizing black walnut silviculture. Experimentation has necessarily included seed collection, nursery practices, planting, and plantation cultural practices. By combining these results with the results of research efforts elsewhere, primarily in the Midwest, considerably more is now known about the silviculture of growing black walnut in the Southeast than was known 5 years ago.

## SEED COLLECTION

For nursery production most black walnut seed are now collected without regard to source. Recent pub-

lications indicate that seed source may be important in black walnut (Bey *et al.* 1971, Wright and Lemmien 1972). Bey (1972) reported that seed from southern sources produce trees whose leaves flush earlier and drop earlier, grow taller, and have more lateral buds on the current year's terminal than trees from northern sources. Deneke and Funsch (1970) found survival higher after two growing seasons for southeastern sources than local Kansas sources.

Because of the range in elevation within the Southeastern Region, it is suspected that growth patterns differ significantly among physiographic provinces. The State forestry agencies of North Carolina and Virginia have separate geographic seed source studies underway to determine if seed collection should be segregated by physiographic provinces; i.e., the mountains, piedmont, and coastal plain. The study in Virginia has seed sources from elevations of 500 to 2,000 feet; the one in North Carolina from elevations of less than 100 up to 3,500 feet. Answers should be available in 3 to 5 years.

## NURSERY PRACTICES

Seedling size, provided the seedling has an adequate root system, is perhaps one of the most reliable indicators of growth potential when the seedling is out-planted. Most studies to date indicate the larger the seedling diameter at root collar, the better the height growth. The maximum feasible root collar diameter has not yet been determined; the economics of producing the seedling in the nursery will certainly be one limiting factor. A minimum root collar diameter of one-half to three-fourths of an inch has been suggested by the hardwood silviculture foresters of the North Carolina Forest Service.

Essential for the growing of large seedlings is an abundance of water, proper fertilization, and proper seedbed density. It is doubtful that current fertilization regimes are the best and more work is required in this area. To attain the desired seedling, a density of no more than five per square foot is recommended.

When seedlings are lifted, care must be taken to ensure that as much of the root system as possible is left intact. Large diameter seedlings need large fibrous root systems to support the shoot.

## PLANTING CONSIDERATIONS

### Methods

Seedling planting has been far more successful than the planting of nuts. By planting the proper size seedling, at least 2 years' growth is gained. Rodent damage and vegetative competition are also reduced.

The planting of potted black walnut by the North Carolina Forest Service during the summer months has been successful. Planting 2- to 3-month-old seedlings in 5-inch diameter by 7-inch-high peat pots resulted in survival averages over 90 percent, except where the peat pots were not placed below the soil surface. If left exposed, the pots act as a wick by absorbing soil moisture from the root zone and transpiring the moisture into the atmosphere. The planting season could be extended into the summer months with the use of potted seedlings.

Large, bare-rooted seedlings must be carefully planted. The shovel is the best planting tool for large root systems, but the posthole digger, mattock, and power auger are also good. The power auger is fastest, but if the holes are made too deep a depression occurs from soil settling after planting that may allow standing water.

To allow for soil settling, the seedling should be planted deep enough so that the root collar is 1 to 2 inches beneath the soil surface.

## Association Plantings

European black alder and black locust are currently being alternately planted with black walnut. Both species are known to increase the available nitrogen thereby increasing black walnut growth. Presently, European black alder is favored because of its exceptional growth, and the prospect that the trees can eventually be sold as pulpwood for additional income. No known association plantings are old enough to determine whether detrimental effects may occur, such as overtopping of the black walnut by the nurse species.

## SITE SELECTION AND PREPARATION

No silvicultural practice can rescue a black walnut plantation on an unsuitable site. Desirable sites in the Southeast are deep, fertile, well-drained, loamy soils usually found in the small stream bottoms and terraces, and the mountain coves. Moisture is probably the most critical site factor. Too much or too little moisture is devastating, but no definite upper or lower limits have been determined. Black walnut can tolerate some flooding, provided the water leaves in a few hours. One successful planting was flooded four times the first year and at least twice annually the next 3 years. Water never remained more than 24 hours except in a small area where the trees died. Such a difference in microsite is easily overlooked, but is extremely important.

The planting area should be free of competition. Plowing, disking, hand tools, and chemicals are satisfactory means of controlling competition. However, the best growth achieved by the North Carolina Forest Service has been on "bedded" sites.

Bedded sites are planting beds raised 10 to 15 inches in height and measuring 3 to 5 feet in width. Beds are formed with standard bedding plows, large roto tillers, or farm plows. Bedding creates a planting medium with better soil aeration and better soil water percolation in the feeder root zone. The major advantage is decreased weed competition in the first year after planting. Before planting, the beds must be allowed to settle preferably for several months; at least two heavy rains are also required. So impressive have been the results, that bedding is now recommended for all black walnut plantings in North Carolina.

## CULTURAL PRACTICES

### Weed Control

Woody vegetation, grasses, and vines compete most severely with black walnut; herbaceous plants compete very little and their effect on growth is negligible.

Hand tools have been used for weed control with success but chemicals are better, less expensive, and easier (see page 114). A pamphlet, *Weed Control in Black Walnut Plantings* (Krajicek 1969), is suggested for more complete information.

### Fertilization

Better knowledge of the soil nutrient requirements for optimum growth of black walnut is needed. Serious nutrient imbalance, however, can be detected by chemical analysis. Thus, representative soil samples should be taken on a prospective planting site. A fertilizer, chosen on the basis of the analysis, should be applied before or at the time of site preparation to bring the site up to suggested nutrient levels.

After planting, fertilization is generally not recommended in the early years nor at the time of coppicing because it can stimulate undesirable growth in the seedling and increase competition from weeds. Overstimulation from fertilizer has resulted in heavy top growth and succulent stems subject to breakage from wind or their own weight. The one case in which fertilizer is

applied to young trees to stimulate growth is when a young plantation has not started growing after 2 years in the field.

### Side Pruning

The side pruning studies in the Southeast are for the most part less than 4 years old. No side pruning should be done until after the third growing season, perhaps longer. Large limbs that will not callus over quickly should not be pruned. Clark (1971) suggests that no limb over 1 inch in diameter should be pruned. Pruning has been done as late as April in North Carolina without any apparent detrimental effects; thus, side pruning anytime during the dormant season is considered satisfactory. To maintain tree balance, no more than one-half the length of the tree should be without side limbs.

### Corrective Pruning and Coppicing

The high incidence of dieback is the most frustrating silvicultural problem in growing black walnut. Multiple stem tops are a common occurrence, especially in the early years. When a tree with a poorly formed top has less than the minimal 9 feet of potentially straight stem, either corrective pruning or coppicing is required.

Corrective pruning is recommended only to release a leader which will maintain an acceptable stem thereafter. Results show that if corrective pruning must be applied to a tree for more than 1 year, stem crook often becomes too great to achieve a desirable stem. If this occurs, no choice exists but to coppice.

Coppicing is the best way to correct poorly formed trees with less than 9 feet of acceptable stem. Tests in both natural and planted black walnut indicate that coppicing can be done anytime during the dormant season. Stems should be cut at an angle less than 2 inches from the ground. Once a 9-foot high acceptable stem is attained, coppicing should not be considered.

Multiple stems usually occur after coppicing. Present recommendations are to select the most vigorous, straight sprout in the early spring following coppicing. Other sprouts should be removed immediately to encourage more growth on the selected sprout.

## ACCEPTABLE GROWTH AND SILVICULTURAL GOALS

Most black walnut seedlings grow very little the first year after planting, but should accelerate in growth the second year. Although growth will vary widely by sites, by the fourth year it should exceed a foot per year. Anything less indicates that something is wrong—improper site, poor seedlings, poor site preparation, inadequate weed control. Growth in black walnut plantings in the Southeast has varied from poor to excellent. Poor growth can usually be traced to not following a recommended practice. Best growth in a young plantation averages 15 feet after 4 years. To achieve the desired rotation age of 35 to 40 years for veneer logs, early growth is essential.

Seventeen feet of acceptable stem in the butt cut of the tree is the current goal of black walnut silviculture. However, the mills in the Southeast will process logs with as little as 9 feet of acceptable stem in the butt cut.

## NEEDED RESEARCH

Considerable progress is being made toward making the growing of black walnut in the Southeast more profitable, but problems do exist which hinder our program. Continued and new research are needed on:

- (a) Geographic variability of seed source in the Southeast.
- (b) Upper and lower limits of nursery seedling water requirements.
- (c) Proper fertilizer regimes in the nursery.
- (d) Causes of and the regulation of the high incidence of dieback in young trees.
- (e) Fertilization of young plantations.
- (f) Acceptability of fast-growing black walnut for lumber and veneer.
- (g) Improving logging and milling technology so that short logs can be utilized.

## SUMMARY

The Southeast presently has no appreciable volume of quality black walnut sawtimber or veneer timber because of the repeated high-grading of the timber stands in the past. Suitable sites do exist, however, from the coastal plain to the mountains. The furniture industry of the United States is centered in the Southeast and is a readily available market for quality wood. Only recently has the planting of black walnut and the required silvicultural practices been examined in detail. Midwestern growers have made black walnut culture successful and practical through research. Continued experimentation, careful promotion, and the use of known silvicultural methods can achieve the same results in the Southeast. The present goal is to grow a 17-foot butt log suitable for veneer within 35 or 40 years. Problems needing new and continued research are listed.

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# GENETICS AND TREE IMPROVEMENT

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**ABSTRACT.**—Recent progress of walnut genetic research and action programs has been good. It is possible to make considerable genetic gains for growth traits simply by using walnut planting stock of appropriate geographic origin. The prospects for vegetative propagation are now considerably improved, for rooting of cuttings as well as grafting.

Just as with any other crop, the genetic improvement of black walnut consists of determining the extent of heritable variation, identifying and selecting individual plants possessing desirable genetic traits, and interbreeding these trees to produce certified seed. Walnut tree improvement is making steady progress along this course.

The history of black walnut genetics and tree improvement is not really crowded with heroes. Aside from pioneering hybridization by Burbank, and the evidence of racial variation demonstrated by Emerson (1906) and Wright (1954), nearly all early efforts were directed toward selection, breeding, and propagation of improved nut varieties. Until the time of the Walnut Workshop 7 years ago, work on genetic improvement of black walnut for timber production lacked both volume and continuity (Wright 1966). I am pleased to report a considerable upsurge in the volume of walnut genetic research and action programs; if we can maintain the necessary continuity, the prospects for real progress are good.

## PROGRESS

Over the past 12 years, Forest Service research by F. Bryan Clark, myself, and especially by Calvin Bey has confirmed the importance of racial genetic variation in several important characteristics of black walnut (Bey 1973). For most traits of phenology and growth in young plantations, differences among seed sources were considerably larger than differences among trees within stands or stands within areas (Bey 1970; Bey, Hawker, and Roth 1971). The significance of these findings is

that it is possible to make considerable genetic gains simply by using walnut planting stock of appropriate geographic origin; all of our tests to date indicate that seed should be collected from south of the intended planting site.

McKay (1966) characterized vegetative propagation of black walnut as either "unsuccessful" or "unreliable," but the situation is no longer so bleak. Attempts to root cuttings were indeed generally unsuccessful in the past, but Shreve and Miles (1972) have reported striking success in rooting black walnut cuttings originating from adventitious buds. More important, the technique that they used worked as well with mature trees as with seedlings.

Walnut grafting is no longer as unreliable as before. Over a 4-year span, Masters and Beineke (1973) achieved 81 to 100 percent success for three methods of grafting in the greenhouse and growth chamber. In the field, the success rate for inlay grafting, the best method tested, ranged from 33 to 83 percent. I believe that black walnut continues to earn the distinction of being "perhaps more difficult than any other hardwood species" to propagate (McKay 1966), but we no longer need to be resigned to failure; the job can be done.

Progress in controlled breeding of walnut has been slow and probably will continue to be so. Since walnut flowers usually occur singly or in clusters of two or three, their isolation and pollination is much less efficient than for such species as pines or yellow-poplar in which seed is borne in cones. The techniques of controlled pollination carried out most extensively by Tucovic in Yugoslavia are not unusual, but seed set is often very low. Some progress has been made in im-

<sup>1</sup> Laboratory maintained in cooperation with Southern Illinois University.

proving methods for long-term storage of pollen to allow making otherwise impossible crosses. We can now systematically verify the hybridity of walnut seedlings of some of the common species combinations. But at least for the near future, most of our breeding work will be based on open-pollinated seed.

Over the past few years, several State forestry agencies and the National Forest System have taken steps to maintain better control over the sources of their walnut seed supply. At least four States and National Forests have developed seed production areas that are bearing on a regular basis. And nine States and National Forests have established seed orchards that will add an important contribution to the walnut seed supply when they come into full production. Many nurserymen have divided their States into regions and ship walnut planting stock to tree planters for use in the same area in which the seed was collected. Industrial cooperators are also working to ensure that the seed they provide to the States is kept separate by collection zones and distributed to appropriate nurseries.

A less tangible component of progress in walnut genetics is cooperation. University, industrial, State, and Federal tree improvement workers have formed an unusually close network to expedite seed collection and exchange, planting stock production, experimental plantation establishment and maintenance, data collection, and sharing of results and recommendations. To cite an example from our program at Carbondale, in addition to field studies located on our own experimental areas using our own personnel, we depended on cooperators to help establish at least 42 separate walnut research plantings in 15 States. Most of these plantations are thriving, being actively managed, and yielding increasingly useful information. Intensive and enthusiastic cooperation has been absolutely essential to get the job done.

## WHAT NEXT?

Understandably enough, selection in most walnut genetic improvement programs has been directed toward climatic adaptation, increased growth rate, and improved tree form. We have a long chore ahead of us before achieving maximum progress with these objectives, and now is certainly no time to relax the effort. But I suggest that as we begin to make some genetic progress toward these original goals, we should broaden our effort to include improved seed production and pest resistance. From the forest tree improvement standpoint increased seed producing capability has obvious benefits to seed

orchard managers; I believe that this trait will be even more valuable in terms of breeding dual-purpose trees for production of both nuts and timber. Inherently pest-resistant trees are obviously desirable and there is no doubt that insect and disease problems seem to be greater in intensively cultured plantations than in natural stands. These difficulties are likely to be compounded as we are faced with increasingly stringent restrictions on use of pesticides; the search for genetic pest resistance may provide the *only* acceptable solution.

Tree improvement and tree planting must and should be tightly linked. A large tree planting program justifies a comparable tree improvement effort because the genetically improved planting stock can be used on a broad scale. Conversely, seed and seedlings of the highest genetic quality are of little value if they are not used in reforestation, either because their superior worth is not recognized or simply because there is generally little demand for the species. Such is certainly not the situation with black walnut. The demand for planting stock has quadrupled over the past 10 years to total more than three million seedlings and stratified nuts shipped by State nurseries each year (Williams and Phares 1973).

The opportunity is at hand to plant improved walnut trees on a broad scale. But tree planters are not receiving the genetically superior planting stock that they need. Why is this so? I believe that there are at least two underlying problems and perhaps three solutions to them. The first problem is the scarcity of improved seed, and in some years, a general shortage of walnuts over large portions of the range. A short-term solution to this problem is to improve methods of seed storage so that good crops can be held over until later years; this sort of information should be available in the near future. A long-term solution to the problem lies in one of our specific objectives: creation of orchards with sufficient capacity to supply the needed seed.

Another problem related to the shortage of genetically improved walnut planting stock is that we are simply not doing the best job we know how to do. I mentioned in complimentary terms the development of seed production areas and seed orchards, establishment of seed collection zones and other real progress that has been made in the past few years. But the fact is that much of the walnut planting stock shipped today is of unknown or unsuitable geographic origin. We all know the reasons, "We ran out of seed and had to buy from Siberia," or "I know that we should collect seed from that area, but we aren't allowed to cross the river." Nevertheless, the

tree planter who receives seedlings or seed of improper origin has to live with *our mistakes* for the life of his plantation. It's time to shape up.

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# GENETIC VARIATION AND SELECTION

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**ABSTRACT.**—Research dealing with genetic variation and selection in black walnut has confirmed the idea of wide genetic diversity. Growth, form, leaf flush, leaf fall, and period of growth are genetically variable. Leaf flush usually begins 1 day earlier for every 85 miles south of the planting site that seed is collected. In field tests, leaf fall is delayed about 1 day for every 25 miles to the south that seed is collected. Trees from as far as 200 miles south of the planting site generally grow as large or larger in height and diameter than trees from local or northern sources.

Where variation exists, we have a choice. We don't have to be satisfied with brand X; we select the brand that pleases us most. The same thing is true in tree improvement. We compare trees of various origins with some standard (brand X) and then select the trees that please us most. For a given character, the amount of improvement possible depends largely on the degree of genetic variation present, or on how superior the selected tree is compared with a standard.

Fragments of genetic information available before 1966 suggested that there were good possibilities for genetic improvement of black walnut. Reports of trees growing in plantations north of their natural range suggested that there was inherent variation in cold hardiness. The many named nut varieties of black walnut showed that variation was present in nut and kernel characteristics. Coupled with this evidence of variation, we knew that walnut grew on diverse sites, over a wide range of climatic conditions, and that it was primarily an outcrossing species. There was reason to begin research and improvement programs on an optimistic note.

During the past 7 years, research and action programs have confirmed the idea of wide genetic diversity. Growth, form, leaf flush, leaf fall, and period of growth are some characters that are genetically variable. Nursery results in a range-wide seed source study showed that for most characters studied there was a gradual increase or decrease from north to south. Results from outplantings at many locations have supported this variation pattern.

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<sup>1</sup> The Station's laboratory in Carbondale is maintained in cooperation with Southern Illinois University.

The relative importance of geographic variation (among stands) and local variation (within stands) has been studied. Evidence is clear that geographic variation is several times greater than local variation for most characters. The importance of using the proper geographic source of seed cannot be emphasized enough. On the other hand, local genetic variation is large enough so that it should not be ignored in improvement programs. In other words, within a designated seed collection zone, there is additional opportunity to make genetic gain through selection.

## CHARACTER VARIATION

### Seed Size

There is a wide range in seed size but no geographic area produces unusually large or small seed. Average fresh weight of seed from 456 individual trees representing 69 geographic sources was 22 grams. Average seed weight varied from 5 to 40 grams for individual trees and from 12 to 30 grams for sources. The average seed weight for individual trees within the same source differed by 10 grams or more in more than half of the sources. Much additional work has been done on nut traits, but it is not included here as we are dealing primarily with timber traits.

### Survival

In 6-year-old provenance tests in Illinois, Missouri, Indiana, Kansas, Iowa, and Michigan, survival was *not*

related to the latitude of the sources. The sources included in these tests were generally from 200 miles north to 400 miles south of the planting site. In an Ohio provenance test, survival after 6 years was generally higher for the southern sources. The trend was weak, however; only 30 percent of the variation associated with survival was accounted for by the latitude of seed source. In a 6-year-old Minnesota test, there was a strong continuous trend with latitude, with higher survival in trees from northern sources (all sources were from south of the planting site). Seventy-six percent of the trees from 250 miles south of the planting site survived, while only 29 percent of the trees from 250 to 650 miles south survived. Seventy-nine percent of the variation associated with survival was accounted for by the latitude of seed source.

## Leaf Flush

Trees that break dormancy early are more susceptible to spring frost damage than late-flushing trees. The time of black walnut leaf expansion in the spring has been studied in five plantations located in Michigan, Ohio, and Illinois. Flushing was recorded in 1969, 1970, and 1971 in one Illinois plantation and in 1971 in the other four plantations. Leaf flush is considered to have occurred when the first leaf on the tree is 1 inch long.

In all plantations trees from the southern sources flushed earlier than trees from northern sources. On the average, flushing began 1 day earlier for every 85 miles south of the planting site that seed was collected.

As would be expected, trees in northern plantations generally flush later than trees in southern plantations. In plantations in Michigan, Ohio, and Illinois, flushing in 1971 was delayed about 4 days for every 100 miles to the north that the plantation was located. However, local and microclimatic environmental conditions can influence the date of leaf flush. For instance, on two southern Illinois sites about 15 miles apart, trees on an upland site flushed about 4 days earlier than those on a bottomland site. Apparently the soil was drier on the exposed upland site, allowing the soil to warm up sooner than on the bottomland site. Trees from the same families flushed first on both the upland and the bottomland site.

In one plantation in Illinois the average flushing date differed by only 3 days over 3 years of tallying, ranging from April 25 to April 28. Trees that flushed early one year also flushed early the next.

Heritability (the degree to which a character is influenced by heredity as compared with environment) for date of leaf flush was 0.67 and 0.96 in two separate 2-year-old 85-family progeny tests and 0.67 in a 4-year-old 17-family test. Although these high heritabilities indicate that the chances for making genetic gains for this character are good, even with intensive selection it appears that within any seed collection zone we would not be able to delay flushing more than a few days.

## Leaf Fall

In three separate tests, leaf fall showed strong trends with latitude. Trees from southern sources drop their leaves later than trees from northern sources. This information has been known since 1906 when Emerson conducted a test with walnut in Nebraska. In a recent nursery test, leaf fall was delayed about 1 day for every 200 miles south of the nursery that seed was collected. In two field tests, the delay was about 1 day for every 25 miles. Early autumn watering in the nursery usually causes the leaves to hang on longer than normal; leaf fall in the nursery then generally occurs in a relatively short time. In the three tests mentioned, latitude of seed source accounted for 74, 77, and 96 percent of the variation associated with date of leaf fall. In a plantation of 4-year-old trees in southern Illinois, leaf fall in trees from the southernmost sources (Texas and Mississippi) did not occur until after the first hard freeze in 1969. We speculated that trees holding their leaves until late fall might not be winter-hardy. But there was no evidence of winter dieback, so the buds and stems were apparently mature and well hardened. The period between height-growth cessation and leaf fall was about 11 weeks for all trees.

## Height and Diameter

At eight locations (mentioned in section on survival) trees from as far as 200 miles south of the planting site generally grew as large or larger in height and diameter than trees from local or northern sources. Although in Missouri, Illinois, Indiana, and Michigan, sources from more than 200 miles south generally were larger than local sources, we would not recommend going beyond 200 miles south of the planting zone for seed collection for reforestation purposes. In an Iowa and Minnesota provenance test, we found a definite limit on how far northward walnut seed can be safely moved without reducing growth. Trees from sources more than 200 miles south of the planting site generally were smaller than local sources.

Duration of growth and rate of growth are both responsible for some of the growth differences. In 1969 in one southern Illinois plantation, trees from Mississippi and Texas grew in height for 134 days, compared with 93 days for trees from northern Illinois and Iowa. On the average, height growth continued 1 day longer for every 24 miles south of the planting site that seed was collected. Most height growth takes place in a short time. In 1967 and 1968 in southern Illinois, 90 percent of the height growth for the year was completed in 8 to 10 weeks.

Duration of diameter growth is less closely related to latitude of origin than is duration of height growth. One study of 4-year-old trees showed no correlation between latitude of origin and number of days of diameter growth, or between latitude and the date by which 90 percent of the diameter growth occurred. However, trees of southern origin grew faster than those from the north. Differences among the groups gradually increased throughout the growing season.

In a pot study with 1-year-old trees, we found that shoot and root dry weight differences among sources generally increased with time. Although height growth was complete by mid-July, shoot dry weight increased until mid-August and root dry weight increased until mid-September or time of leaf fall.

The importance of geographic variation has also been demonstrated in an 85-family combination progeny test-seedling seed orchard in southern Illinois. The collection zone for the test included an area from 150 miles to the north to 150 miles south of the planting site. At the end of the first growing season, trees in the tallest families (top 20 percent) all came from parent trees located south of the planting site (fig. 1).

### Stem Crook

Although crook is an important negative character, it is difficult to measure in young walnut trees. However, we devised a crook index based on lean, number of crooks, and degree of maximum crook, and measured trees in one young plantation for this character in 1969 and 1970. In neither year were we able to detect any differences for index of crook among geographic sources. In 1969 there were differences among families within source, but not in 1970. Although this study suggests that the potential for making improvement in stem form through genetic selection is not great, it should not be ignored. In the studies reported above, the trees in the tallest families also tended to be the most crooked.



Figure 1. — *These 3-year-old (from seed) trees, growing in a seedling seed orchard in southern Illinois, are being selected and tested for desirable timber characteristics.*

### SELECTING THE BEST

We have shown conclusively that walnut trees are genetically variable. The pattern of geographic variation has been useful as a guide for setting up seed-collection zones. Within collection zones the useful genetic variation that exists among trees is being discovered through progeny testing. Parent trees that prove to be genetically superior can be used as sources of improved seed and grafting stock. In progeny tests the undesirable trees (entire families and smallest trees of the better families) can be rogued and the remaining desirable trees converted to a seedling seed orchard. Cross-breeding among the

desirable trees should also yield improved seed. Trees in a seedling orchard can again be progeny tested, which can lead to a second generation seed orchard. New combinations in the seed orchard may yield additional variation, with an opportunity for even more intensive selection and greater gains in the future.

## FUTURE RESEARCH

Research emphasis in the future should be on finding ways to most efficiently use genetic variation that has been shown to exist. Within and outside the natural walnut range, additional provenance tests can help to define the seed-collection zone more definitively. In future tests geographic areas of seed collection can be reduced. Progeny testing from wide geographic areas may serve the dual purpose of defining more accurately the proper seed-collection zone as well as establishing the genetic worth of individual parent trees.

Obviously, we need to continue collecting data in the studies already underway. By measuring periodically we can evaluate the reliability of early recommendations. Hopefully, this will speed future research.

The effectiveness of phenotypic selection in wild populations has not been established. We need to establish tests where progeny of selected or plus trees are compared with progeny of randomly chosen individuals.

We need to determine the optimum levels of selection in seedling seed orchards. Do we want to save all the trees in the best 25 percent of the families or should we save only the best half of the trees in the best 50 percent of the families? Perhaps some other combination is best. This question needs to be answered as we begin roguing seedling seed orchards.

The selection process is confounded when both desirable and undesirable traits occur in the same tree. The problem can be solved only by compromising on one or more of the traits. We need to establish the trade-offs and pay-offs associated with selection for single traits

and various combinations of traits. Solving this important problem will help us decide which traits to concentrate on in the future. We also need to know how easy or difficult it is to solve problems through silvicultural manipulation. By understanding the relative importance of genetics and silviculture, we can become more efficient in our improvement work.

The problems listed here deal primarily with describing variation and discovering the most effective and efficient methods of selection. Action programs need not wait until all these problems are solved. By taking advantage of what we presently know about seed-collection zones, nurserymen can provide faster growing seedlings today. Continuing research, running concurrently with action programs, will provide the knowledge needed to make additional improvement in walnut seedlings for the future.

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# VEGETATIVE PROPAGATION: PROBLEMS AND PROSPECTS

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**ABSTRACT.**—Problems and opportunities in grafting, budding, and rooting black walnut are reviewed with emphasis on the role of these techniques in developing and using genetically improved stock. Better application of physiological principles should lead to increased production success with currently used grafting and budding procedures. Promising new information suggests that rooting will soon be a reliable technique. Some recommendations are made for future research and the development of propagation systems.

Asexual propagation of black walnut (*Juglans nigra* L.) has been the subject of much study, but is still considered difficult. In this review I hope first to show that proper application of existing physiological information should lead to greater success with some standard grafting and budding techniques, and that recent results from rooting research give new promise to this method. Second, I will present some thoughts on potentially productive approaches for future research and the application of vegetative propagation in genetic improvement and silviculture.

## GRAFTING

The history of black walnut grafting is well-recorded in the annual reports of the Northern Nut Growers Association. Sitton's (1931) and O'Rourke's (1951) reviews cover early efforts, which were characterized by variation in both technique and results. A review of this early work, along with more recent studies, indicates that routine success will depend on several key factors that are thoroughly discussed in modern plant propagation texts (e.g., Hartmann and Kester 1968). In addition to good technique, attention must be given to temperature and moisture conditions conducive to rapid callus growth at the union, control of bud dormancy during union formation, and the nutritional status of stock and scion.

Some of the earliest research on black walnut grafting (Sitton 1931) established that temperatures of 25° to 28° C. and high relative humidity are necessary for

rapid callus growth. It is not surprising, therefore, that outdoor grafting in the generally cool springs of the eastern United States has been frequently unsuccessful. The problem of low temperature in nursery grafting is accentuated by high root pressure, which causes sap flow or "bleeding" sufficient to prevent graft union. The 58 percent success noted by Zarger (1956) and the 70 to 80 percent reported by Lowe and Beineke (1969) for cleft and bark inlay grafts are considered to be exceptionally good under the commonly adverse field conditions. By grafting in late May when temperatures averaged 18° to 20° C., Mittempergher (1969), working in Italy, obtained 82 percent success.

Beckert (1961) has noted that root pressure can be reduced by grafting to freshly transplanted stock. Bleeding problems may also be reduced by severing tops several days before grafting or by cutting release openings in the stock below the graft (Chase 1947, Graves 1966, Hartmann and Kester 1968, Maurer 1967). In addition to these procedures for reducing root pressure, Lagerstedt and Roberts (1973) successfully used plastic covers over grafting beds to maintain temperatures suitable for callus growth of Persian walnut (*J. regia*).

Bench grafting avoids some of the environmental problems inherent in field grafting because temperature and moisture conditions during callus formation can be easily controlled. It has long been used with some success in both winter and early spring (Kemmer 1935, 1938; Lounsbury 1937; Sitton 1931). The keys

to success are the induction of rapid callus growth leading to union formation, and control over bud dormancy. Late fall bench grafting using the method of Cerny (1965) is done while buds are physiologically dormant. Grafts are stored in a warm (22° to 28° C.), moist environment until callus is formed, then transferred to a cold environment (4° C.) to complete chilling requirements of buds before spring planting; Pieniazek (1972) reports up to 90 percent grafting success using this procedure in Poland. Essentially the same procedure can be used in winter and early spring if care is taken to ensure that buds, which may have completed chilling requirements, do not begin growth before callus is formed. This can be accomplished by placing grafts vertically in a sawdust-filled, cable-heated hotbed with unions exposed to 21° to 27° C. and buds exposed to chilling temperatures. Lagerstedt (1969) correctly notes that this hotbed technique is also suitable for fall grafting.

Standard spring bench grafting with entire plants exposed to warm temperature immediately after grafting has also been successful, especially under greenhouse conditions (Slate 1948, Dykstra 1971, Beck 1972, Boer 1954, Komanic 1967). Shreve has found that it is helpful to place bench grafts under intermittent mist during union formation.<sup>1</sup> Auxins have been used effectively to promote rapid callus formation (Brierly 1953).

While many *Juglans* species and hybrid graft combinations appear to be compatible during early growth (Kaeiser and Funk 1971), there is evidence of delayed incompatibility or "blackline" of *J. regia* grafted on *J. hindsii* (Serr and Forde 1959), and of *J. regia* on *J. nigra* (Glenn 1965). In Oregon the "blackline" problem has been solved through the use of "man-regian" walnut rootstock (Lagerstedt and Roberts 1973). Weschcke (1948) reports that differential growth rates eventually cause failure of *J. cinerea* on *J. nigra*. Reports of variation in grafting and budding success among genotypes suggest that intraspecific incompatibility may exist (Maurer 1967, Zarger 1945).

## BUDDING

Budding, as well-described in several handbooks (e.g., Jaynes 1969, Hartmann and Kester 1968), has

<sup>1</sup> Personal communication with Loy W. Shreve, Extension Forester, Kansas State University, Manhattan, Kansas.

been used about as frequently as grafting in walnut propagation and is characterized by some of the same physiological problems. In addition, some difficulty has been experienced in obtaining renewed growth of the buds after successful union with stocks.

Two basic approaches have been used. First, fully developed buds in a state of imposed dormancy (i.e., chilling requirements completed and dormancy maintained by cold storage) may be grafted in spring and early summer, after which they immediately develop into shoots. Most of the more successful workers (e.g., Gerardi (1954), Becker (1964), Shelton (1954), and Chase (1947)) have used patch or chip budding. Budding in late May or June appears to be preferable to early spring budding. The advantage of this approach, of course, is that a budded plant is produced in one season by gradually reducing stock leaf surface (Becker 1964) and concentrating growth in shoots originating from grafted buds. Root pressure has been as much a problem with budding as with grafting, and procedures for its reduction have been noted above. Tuttle (1947), who used T-budding, recommended a longer than normal vertical incision in the bark to allow for drainage.

The second general approach consists of budding current-year quiescent buds in late summer. Unions are formed in summer and fall, then buds are forced the following spring. This procedure has generally been more successful than spring budding. Plate (Stoke 1937), patch (Zarger 1957, Cummings and Zarger 1945), modified-patch (Davis 1962), chip (Becker 1964), and T-budding (Gerardi 1954) all have been used. While union of the bud patch and stock plant is apparently not difficult to obtain and takes place in about 60 days (Nedev 1969), failure of buds to survive winter and to renew growth in the spring has frequently accounted for low success, especially for some interspecies budding (Davis 1964, 1965). Operational success of about 50 percent has been reported for black walnut nut-production varieties by Cummings and Zarger (1945) and Zarger (1957).

A detailed study of the relationship between budding success and the developmental stage of summer buds when taken for budding might be helpful in elucidating the causes of bud failure. For example, there may be some stages of meristem development at which budding shock may disrupt normal development and entrance into dormancy. However, it is probable that

most failures are related to the slow development of callus immediately subsequent to budding and can be avoided by: (1) using stocks and bud wood of high physiological quality, and (2) careful maintenance of moisture and temperature conditions suitable for rapid callus growth. The use of auxin-like growth regulators to promote vigorous callus formation under budding conditions needs investigation.

## ROOTING

Rooting black walnut cuttings has been considered very difficult, though the literature contains few reports of negative results. Recent promising efforts suggest that we may have been intimidated by the reputation of the species.

Success with trench layering has been reported for the Paradox hybrid walnut by Serr (1954), and for black walnut by Solignat and Venot (1966) and Cummins (1970), who reviewed previous work with this technique. Bey (1967) and Zatyko (1967) used the split seedling procedure to obtain genetically identical pairs. Rooting by this means, however, is relatively expensive and not readily adaptable to mass production of single genotypes.

Lynn and Hartmann (1957) rooted softwood cuttings of the Paradox walnut in a mist bed after a quick-dip treatment with indolebutyric acid (IBA). The first successful efforts with black walnut cuttings were reported by Fourcy *et al.* (1965) who rooted slightly etiolated juvenile shoots under mist after treatment with IBA. An adaptation of this procedure by Farmer (1971) incorporated juvenility, etiolation, girdling, and auxin treatment. Subsequent work (Farmer and Hall 1973) using auxin pretreatment of etiolated shoots produced an average of 50 to 60 percent rooting, and material from some stock plants rooted 80 to 100 percent. However, the most successful average rooting to date (about 80 percent) is that reported by Shreve and Miles (1972) using standard propagation techniques. Unetiolated physiologically juvenile cuttings were given a quick-dip IBA (5,000 to 8,000 p.p.m.) treatment and rooted in peat:perlite (1:1) under intermittent mist. Shreve and Miles emphasized that it is crucially important to obtain material originating from "adventitious" buds; i.e., those not externally visible prior to shoot elongation. Material used by Fourcy *et al.* (1965) and Farmer (1971) was of this origin. In preliminary trials, Shreve and Miles noted that "adventitious" shoots originating from grafted Thomas variety black walnut also rooted. Survival of rooted

cuttings has been about 75 percent, and gibberellic acid has been found to be helpful in initiating new shoot growth after rooting (Farmer 1971).

Several aspects of rooting should be investigated. First, some anatomical attention should be given to the origin of rootable shoots. While the term "adventitious" is commonly applied to shoots not originating from obvious axillary buds, it is likely that many of these shoots develop from supplemental axillary buds, not truly adventitious ones. Strictly speaking, adventitious buds arise without benefit of a connection with the apical meristem or tissue recently derived from it (Romberger 1963). Thus, rootability in walnut may be related to the stage of meristem development represented in dormant axillary buds. Both true adventitious shoots and those from suppressed axillary buds may retain the juvenile characteristics of rootability. Second, since evidence to date indicates that physiologically suitable material may be the key to rooting success, methods of producing these shoots from selected older genotypes are essential. Shreve and Miles (1972) suggest that grafted or budded shoots from such trees may be pruned or debudded to force growth of rootable shoots. Use of this technique might lead to development of stool beds or pollards for the production of selected material. Research on such a system should proceed along with further testing of shoot rootability.

Third, improved environmental conditions in the mist bed and use of chemical rooting simulators need to be incorporated into a system that will combine all factors known to enhance rooting. For example, supplemental carbon dioxide, high-intensity lighting, mineral nutrient sprays, and optimum temperatures can now easily be combined in a single mist bed. Recent success with propagation of some difficult coniferous species (Hare 1973) indicates that certain combinations of conditions can improve rooting.

## USE OF VEGETATIVE PROPAGATION

Vegetative propagation by grafting and budding has long been important and economically feasible in black walnut nut culture because of a high broad-sense heritability for seed characteristics. Selection and propagation of clones with good nut qualities has been the central feature of improvement efforts. There are also reports of cloning genotypes with potential for figured wood (Bailey 1948, Wilkinson 1948, Walters 1951), though the reliability of this is still uncertain (McDaniels 1953).

More recently, vegetative propagation has been used to retain genotypes selected for their potential as parents in breeding programs aimed at improved timber production. The central feature of one breeding approach is the clonal seed orchard, or breeding arboretum, which contains a number of selections (Masters and Beineke 1973). In such a breeding situation it will be desirable, though not essential, to have clones growing on their own root systems. The major advantage of rooting will be that propagation costs should be considerably less than for grafting or budding once production systems are developed.

Systems for producing rooted cuttings may also be used directly to supply selected clones for timber production. However, breeding efforts aimed specifically at clone production will be required before attempts in this direction are made. It is unlikely that heritability for growth rate will be anywhere near as high as that for seed characteristics, and therefore clone selection for growth rate will require careful formal testing. Extensive plantings of small numbers of clones also present risks, though dangers of limited genetic variation should be less in the species mixes recommended for walnut culture than for species grown extensively in plantations (e.g., eastern cottonwood). The various problems and opportunities of forest production using clonal selections should be investigated in conjunction with current rooting research.

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# TREE IMPROVEMENT ACTION PROGRAMS — THE MISSOURI STORY

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**ABSTRACT.**—Missouri's black walnut (*Juglans nigra* L.) tree improvement action program is cooperative between the USDA Forest Service and the Department of Conservation, Forestry Division. The program consists of a long-term single tree selection-progeny test-seed orchard (SPSO) development phase, and a short-term phase. The short-term phase includes super-sized seedling production, seed collection, and seedling distribution to specific geographic zones, concurrent provenance testing, and seed production area (SPA) development.

The Missouri Tree Improvement Project was initiated in 1967 with the avowed purpose of improving the quality of the forest trees grown in Missouri through the application of known genetic principles and techniques. The primary emphasis of the program is on improving black walnut, but we also work with other species. This paper will only summarize our work with walnut.

This project is a cooperative program between the Forestry Division of the Missouri Department of Conservation and the Forest Service of the U.S. Department of Agriculture. The authority for the cooperation is contained in Title IV of the Agricultural Act of 1956. We have one forester assigned to this project on a full-time basis, but all of our foresters and nonprofessional employees are available for part-time assistance with tree improvement activities.

Approximately 80 percent of our tree improvement efforts are spent working with black walnut. Our nursery people feel that we have a demand for 500,000 walnut seedlings per year. It takes 6,000 bushels of fruit to get that many seedlings. We would like to meet this demand with improved strains of walnuts selected for fast growth, good timber form, and quality nut production in volume (fig. 1). We plan to achieve this goal primarily through the single tree selection-progeny test-seed orchard (SPSO) development process.

## SPSO PROGRAM

So far, we have located, selected, and cataloged 120 superior walnut phenotypes (parent trees) in Missouri. We primarily select phenotypes that are 10 percent or

more taller, are 10 percent and better in apical dominance (the proportion of total height that is a single stem), and have superior form compared to other walnut trees nearby. In addition, we select for superior nut traits and for superior volume production of nuts. Occasionally we have to select a tree because we just like the looks of it, and there are no comparisons available.

In addition to our Missouri selections, we have 12 selections from Kansas, three from Nebraska, two from Iowa, and one from Illinois. The USDA Forest Service group from Carbondale is furnishing us with 37 families from their collections of walnut for spring (1973) planting. We also have seedlings outplanted from two trees in North Carolina and from one in Tennessee. We eventually hope to test offspring from superior walnut phenotypes throughout the entire range of the species.

We have established three half-sib (having only one known parent) seedling progeny test plantations in three different geographic zones of the State. In addition, we are establishing three more test areas in two additional zones in 1973 (fig. 2). These areas will eventually total 60 acres in five different geographic zones, and we will have about 80 different families, plus several improved nut varieties, in the test areas after 1973.

Our second-year measurements of total tree height and survival have been summarized for those selections already outplanted at the three test sites. Survival of all sources has been satisfactory at all test sites. General observations of height growth indicate that southern sources have been erratic in their performance, and that northwestern sources seem to perform well when moved south and east. However, results are too unreliable at



Figure 1. — *The Missouri Tree Improvement Project is striving to produce strains of walnut trees that grow fast and develop into high quality trees such as this.*

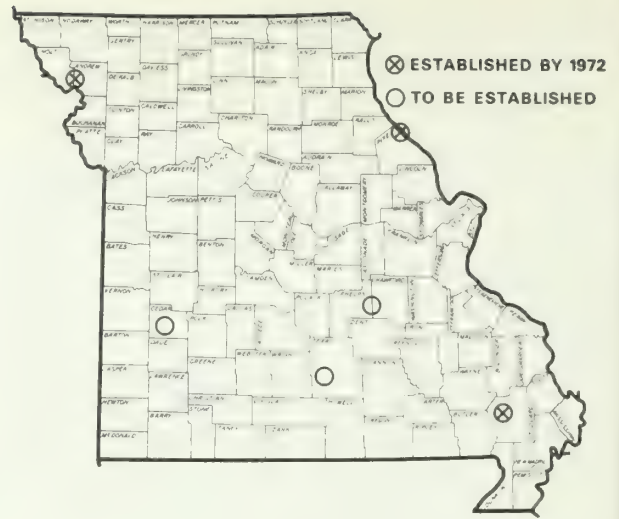


Figure 2. — *Walnut progeny test-seed orchard sites, Missouri Tree Improvement Project.*

this age to be definitive, so we will have to wait for the trees to grow for a while longer before we start drawing too many conclusions.

As these plantations mature, they should indicate which individuals and families of walnuts are indeed superior. We will rogue the inferior trees from the stands and will eventually have converted these test areas to seed orchards to produce seed for our nursery.

The SPSO approach is a long-term program. In order to effect some immediate improvement with walnut, we have done several other things which we think will help.

## SUPER SEEDLINGS

For the last 10 years, our nurseryman has been grading-out the largest 0.1 to 1.0 percent of the nursery-run walnut seedlings, and we have been selling them as "super seedlings." These 1-0 seedlings are  $\frac{3}{8}$ -inch or larger in stem diameter measured 1 inch above the root collar. The fact that these larger seedlings survive and grow better has been shown in studies conducted by the USDA Forest Service (Williams 1966; Williams 1970).

The name super seedling has been construed by some to imply genetic superiority. This is not necessarily so. Perhaps a better name for them would be super-sized seedlings, because that is what they are. No genetic superiority implied.

Our production of "supers" varies from year to year, but it averages about 6,000 seedlings per year. Our highest number was 9,000 in 1972, and we have had as few as 2,000. We would like to increase the average amount to around 10,000 per year if possible.

In addition to the super-sized seedlings, our nurseryman always tries to produce the highest possible quality in all of his walnut seedlings. Even in seedlings of known genetic origin, you must have a seedling with good buds, a balanced root-top ratio, and a satisfactory stem diameter in order to get good initial survival and growth.

### SEED COLLECTION, SEEDLING DISTRIBUTION, AND PROVENANCE TESTING

In 1967, we started to collect seed by geographic zone, grow the seedlings separately, and ship seedlings back to the local zone where the seed originated (fig. 3). We are still doing this today.

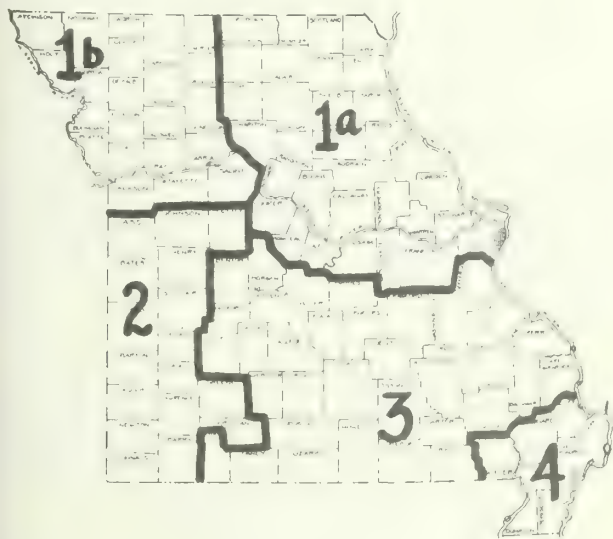


Figure 3. — Walnut seed collection and seedling distribution zones for Missouri.

Concurrently, we have established six provenance tests which should help us to determine if geographic races of walnut exist within the State (fig. 4). This data will aid us in deciding whether or not gains in growth can be attained by shipping seedlings out of their local zones. These tests are currently in their fourth growing season, and they have yielded some second-year data.

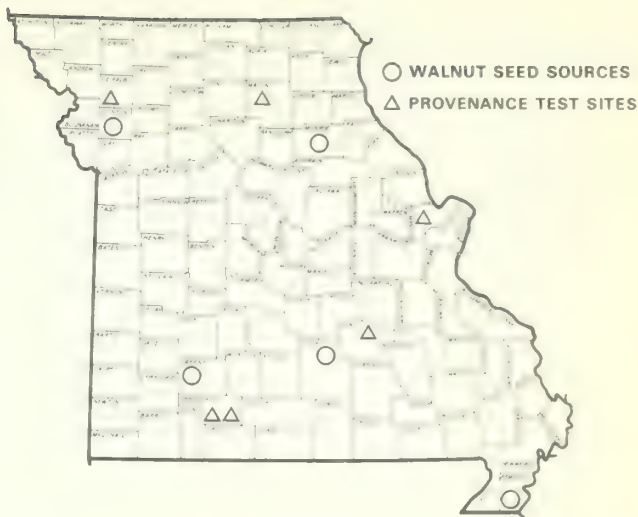


Figure 4. — Walnut seed sources and provenance test sites, Missouri Tree Improvement Project.

After 2 years, survival at all tests was adequate to fully stock the site. Local seed survived best in only three of six tests, and it did the poorest in two of the tests. It was average in the remaining test.

Total tree heights were quite variable, and some significant differences were found. However, we are hesitant to put much reliability in these 2-year-old trees. For the characters measured thus far, there has been no definite north-south growth pattern emerge. There might be an east-west growth pattern emerging, and the south-west prairie area seems to produce shorter trees in all zones. The definite conclusion of the tests is that we will have to wait for the trees to grow some more in order to obtain more reliable data (Brunk 1972).

### SEED PRODUCTION AREA DEVELOPMENT

Another of our temporary improvement steps was initiated in 1967. We have, since that time, developed three seed production areas (SPA's) in existing walnut stands (fig. 5). These total 20 acres, and we collect seed from them whenever there is a crop. Even though we do not, necessarily, know the heredity of the SPA stands, we feel that there is some improvement in the seedlings produced, because of the roguing of inferior phenotypes from the SPA's. Seedlings from our SPA's are being tested in progeny tests, in order to compare them with seedlings from known, superior phenotypes.



Figure 5. — Seed production areas, Missouri Tree Improvement Project.

Our distribution of SPA seedlings has been even more variable than the distribution of super-sized seedlings. Some years we have not had a crop in any of the areas. In 1972, we were able to distribute 9,000 seedlings from the DuPont SPA, and in 1973 we distributed about 3,000 seedlings from the Van Meter area. We would also like to increase these amounts to at least 10,000 seedlings per year from each SPA.

## THE FUTURE

Where does the Missouri program go from here? First of all, we will continue with our SPSO program. We will start cloning (reproducing vegetatively) some of our better selections because they just do not seem to want to produce any seed. Why some of these select trees do not produce seed is beyond me. Many of them appear capable of seed production...i.e., large crowns, vigorous, in a dominant position, etc. Perhaps they are too busy producing fiber, with no energy left over for sexual activity. Perhaps they produce mostly male flowers... or their flowers get killed by frost... or... they are out of a sufficient pollen flow at flowering time... or... who knows?

Our cloning procedure will probably revolve around the rooting technique as described by Shreve and Miles (1972). We will also have to do some grafting I am sure.

Eventually, we will try some hybridization work. We do not visualize much hybridization work between *Juglans nigra* L. and other *Juglans* species, but we do feel that we will try some crossing between the better selections of the native walnut.

We will probably not get into mass selection over the range of the species. This is essentially the work of the USDA Forest Service group at Carbondale, and they are better equipped for it. In all of our tree improvement activities, we always attempt to cooperate fully with other States, universities, private groups, and Federal agencies who might be doing similar work. Life is too short and our goals are many, so we cannot spend time duplicating efforts.

We will do additional provenance testing, and we will probably modify our seedling distribution plans based on our provenance tests. We will also have to modify our half-sib approach in the SPSO program because of the cloning that will be necessary in order to reproduce some of the phenotypes.

## SUMMARY AND CONCLUSIONS

In Missouri, our goal in improving walnut is increased production of quality trees on the limited land base that will be available for growing trees. Ours is an action program that grows trees in the ground, and not on paper.

Our principal approach is through a single tree selection-progeny test-seed orchard development program (SPSO). In addition, we have initiated zoned seed collection and seedling distribution, the development of seed production areas (SPA), provenance testing to determine geographic variation, and distribution of super-sized seedlings for high initial survival and growth.

Our future plans call for more of the same, but with some modifications, based on our provenance and progeny tests, and on our need to reproduce superior phenotypes by cloning. We will probably do some hybridization work among *Juglans nigra* L. selections.

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# UTILIZATION AND MARKETING OF NUTS

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**ABSTRACT.**—About 60 percent of commercially processed black walnut kernels are repacked for retail sale to housewives. Another 30 percent is used in ice cream, 5 percent in commercial baking, 5 percent in candy manufacture. Sterilization of nutmeats is important in ice cream manufacture. No government standards have ever been established for nutmeat sizes or quality, except for bacterial control. Recently, smaller sized nutmeats including meal have been used for retail distribution and ice cream. The annual supply of salable kernels has been reduced 40 percent in the last decade by cutting of good nut producing trees for lumber, by disease, and by indiscriminate herbicide spraying.

Just as the black walnut tree is considered the "King of the Forest," the black walnut nutmeat is thought of as the "Queen of the Kitchen." Unlike peanuts, cashews, and other table nuts, the strong flavor of black walnut kernels make them useful in the kitchen as a food flavoring ingredient.

About 60 percent of the commercially processed black walnut kernels are sold in bulk to nutmeat dealers who repack them in small 3- or 5-ounce cellophane bags for sale at the retail level to housewives for home baking purposes. Another 30 percent is used in ice cream, 5 percent in commercial baking, and 5 percent in candy.

Each ice cream manufacturer has his own variation of the basic recipe for black walnut ice cream. Most use dry nutmeats blended directly into the ice cream mix. Others prepare nutmeats in syrup. Of prime importance in the ice cream industry is strict quality and bacterial control of the nutmeats. Modern sanitary processing methods and final sterilization of the nutmeats enables the processor to guarantee a raw product free from harmful bacteria.

The 5 percent used by commercial candymakers is mostly for cream chocolate or hard candy centers; black walnut pralines and chocolate-covered black walnut clusters are also becoming a popular item.

Most black walnut kernels for commerce are packed and sold initially in 30- or 35-pound bulk cardboard cartons that are lined with a large polyethylene bag to preserve the high quality of the nutmeats. During proc-

essing the nutmeats are separated into uniform sizes by a screening process. No government standards have ever been established for sizing of black walnut kernels; however, all shellers or processors classify sizes larger than  $\frac{1}{4}$  inch as large,  $\frac{3}{16}$  to  $\frac{1}{4}$  inch as medium, and  $\frac{1}{8}$  to  $\frac{3}{16}$  inch as small. Black walnut bits or meal are also becoming a popular item. Each processor has his own quality standards to provide customer satisfaction. No State or Federal quality standards are established except for controls on bacteria.

Until recent years, most housewives preferred the large-sized nutmeats for home baking. Consequently, most of the large-sized nutmeats were packaged for retail distribution and the medium and small sizes sold to ice cream manufacturers and commercial bakers. Recently, however, partially due to higher quality of the smaller sizes and partly due to prices, all sizes including meal are now packed for retail distribution. The ice cream industry also uses all sizes, although the percentage of each size used varies from plant to plant. This trend is proving to be beneficial to the processor because he is assured of a market for all crops despite their varying sizes and yield.

The rule of thumb in the industry is that 70 percent of all nutmeats should be large, 20 percent medium, and 10 percent small. In some years, however, the nut ceases growing in early summer due to drought conditions and a greater percentage than usual are medium and small. In fact, some crops only produce 60 percent large nutmeats instead of the normal 70 percent.

Closely related to the subject of marketing of black walnut kernels is the discouraging decrease in nutmeats available each year. This decrease is largely due to the excessive cutting of the better nut producing trees for valuable lumber. An increased percent of "bad nuts" further adds to the problem. Studies have shown that *Anthrachnose* disease is the biggest contributor to bad nuts and it is generally believed that indiscriminate spraying of black walnut trees with herbicides is also a cause. Consequently an increasing percent of bad nuts is harvested along with the good and sold to the processor. This has caused a year-by-year decline in the

percent yield of salable nutmeats. Ten years ago a 10 percent yield was average, now about 7½ percent is expected. This reduction in yield, along with fewer trees in the nation available for nut production, has reduced the total annual supply of salable black walnut kernels by some 40 percent in the last 10 years.

From the processor's point of view the cultivation of well managed black walnut orchards and increased nut production are essential for the industry to meet the national demands for higher-quality black walnut nutmeats — the queen of the kitchen.

# UTILIZATION AND MARKETING OF SHELLS

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**ABSTRACT.**—For years the shells from black walnuts were considered a waste product; since 65 percent of the nut is shell, disposal was a costly and difficult problem. However, research and market potential have since shown that walnut shells can be used in a variety of ways. Today black walnut shell is recognized as the best of all the nutshells and the demand has created as much of a shortage for black walnut shells as it has for the lumber and meats.

The use of the kernels from black walnuts dates back to the Indians even before our Pilgrim Fathers, but the walnut shells were for many years considered a waste product. The first recorded commercial use that I can find was for making charcoal. The charcoal from black walnut shells was of a superior quality, especially for use in gas masks during World War I. Since there were no commercial shells at that time, the demand was far greater than the supply, and the Federal government asked all farmers and roadside nut stands to save their shells for this use.

Walnut-shell flour was used in the middle 1930's as a carrying agent for various insecticides, and in 1938 a patent was issued for the use of certain sizes of ground shells in cleaning furs.

It was not, however, until 1938 and 1939 that the first important use of walnut shells was discovered. With the beginning of World War II in Europe all countries involved began to expand their airforces, and several of the allies sent their pilots to the United States for training. The additional use of so many cylinder-type airplanes placed a tremendous burden on all overhaul depots. The cleaning of pistons and cylinder heads had been done with chemicals, solvents, and hand scraping. A cheaper, faster, and better method had to be discovered and the most logical method appeared to be some type of particles in an air blast. The list of items tried ran from sand to cooked wheat. The sand was too hard and would scratch and scar. Wheat was fair but the United States government would not approve its use as it was too important a food item. Ground nutshells were tried and proved to

be the best of any item that had been tested. In fact, one overhaul superintendent made the remark that he thought it was the "greatest invention since women."

After the end of the war the demand and use of nutshells decreased, but their fame had spread and experiments for other uses were being conducted.

The loss of drilling fluids in drilling oil wells, especially deep wells in porous strata, has always been a problem; almost every item imaginable from cottonseed hulls to golf balls has been tried to correct it. In the late forties and early fifties, with a surplus of nutshells, someone hit on the idea of trying nutshells ground to certain sizes as an additive to the drilling mud. The results were outstanding and various patents were applied for. Some of these were issued and some were refused. Black walnut shell was recognized as far superior to any other type of nutshell for this use; however, all types were ground and are still used even though they are inferior to black walnut.

The early 1950's brought about a revolution in the automobile industry. Automatic transmissions, power steering, and power brakes were brought out. The gears in these had to be deburred, polished, and finished to a high degree to eliminate noise. Honing and finishing by hand was too slow and expensive, and with the experience of the airplane overhaul depots on carbon removal, ground nutshells were tried on automotive parts (as well as jet airplane parts). It was so successful that now black walnut shell is used to deburr, polish, descale, and finish many parts in various industries.

The utilization of the shells is now a very important part of the black walnut industry. Usable shells can be recovered from approximately 60 percent of the walnuts that are bought. After the nutmeats are extracted the shells are further broken down. This is usually done by attrition, hammer, or ball-mill methods. The shells are then screened into various sizes; the size used as an abrasive depends on the hardness and degree of finishing desired.

Some of the common uses of black walnut shells besides those already mentioned are as a filler in dynamite, a binder in glue, a marker of photograph records and other molded products, an additive in texture paint, a nonslip agent in automobile tires and on decks

and slippery surfaces, a cleaner and polisher of pre-cast concrete and mosaic tile, and a filter agent for scrubbers in smokestacks. New tests and experiments are being conducted all the time.

Truly black walnut kernels are the queen of the kitchen for nutmeats, the tree is the king of the forest for lumber, and the nutshells are the ace of all ground nutshells for any use.

When you consider the tree, the nut, and the shell, and add this to a multiple-crop concept such as a cow-calf operation with fescue or other grass, you have one of the most profitable operations in the United States today.

# ORCHARD ESTABLISHMENT IN ARKANSAS

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**ABSTRACT.**—Although some black walnut orchards were started in earlier years, production planting for the multiple cropping of nuts, saw logs, and agricultural crops began in Arkansas Soil Conservation Districts in early 1972. Orchard sites were selected by use of the "Woodland Suitability Group" system as used by the Soil Conservation Service. Krajicek's formula was used as a basis for spacing orchards. The planting techniques described assured good survival the first year despite a drought.

Multiple cropping for nuts, saw logs, and agricultural produce is the objective of the black walnut planting program started on Arkansas Soil Conservation Districts in early 1972. This paper outlines the program and reports progress made during the first year.

In March 1972, 6,000 black walnut seedlings were planted on 210 acres of black walnut orchards in 25 counties in Arkansas on 34 ownerships. Approximately 70 percent of the planting stock was 1-0 superior black walnut seedlings provided by the Hammons Products Company Nursery at Stockton, Missouri. The remaining 30 percent was 1-0 common black walnut seedlings, obtained from the Arkansas State Forestry Commission Nursery. At the time of this writing, December 1972, orders have been received for planting over 21,000 superior seedlings on about 700 acres for 80 owners in the 1973 planting season.

## SITE SELECTION

Prior to planting, sites suitable for walnut were selected using soil maps made available by the Soil Conservation Service (SCS). The following Woodland Suitability Groups<sup>1</sup> of the SCS were considered acceptable for walnut: 1o4, 1o7, 2o4, 2o7, 3o4, 3o7; on lower north slopes, coves, and benches 4o7; also 3f9, 3x8, and 4x8 if rockiness is moderate.

<sup>1</sup> For an explanation of Woodland Suitability Groups see: USDA Soil Conservation Service. *Soil survey interpretations for woodlands in the Boston mountains and Arkansas valley and ridges of Arkansas and Oklahoma. Progress Report W-7, RTSC, Fort Worth, Tex. 1968.*

Judgment must be exercised in the use of soils maps. Soil types may intergrade or inclusions too small to be mapped may exist. It is also possible for some soils to be too high in clay, as for example Suitability Group 2o4.

## METHOD OF PLANTING

An adaptation of Krajicek's formula was used as the basis for spacing orchards.<sup>2</sup> The average spacing was 40 by 40 feet (27 seedlings per acre). Holes were dug with conventional farm tractors with a 3-point hitch and mounting a 14-inch-diameter soil auger. A heavy canvas blanket, 6 by 6 feet and having a 20-inch-diameter hole in the center, was laid on the planting spot. A hole was dug 30 inches deep, the soil spilling on the blanket. After the hole was dug about half of the soil was funneled back into the hole with the blanket. The seedling, with roots averaging about 15 inches long, was held at the root collar by the planter, who stepped down into the hole and tamped the soil with his feet while his helpers funneled the remainder of the soil into the hole.

## GRASS AND WEED SPRAYS

After planting a spray mixture was applied in 4-foot-diameter circles around the planted seedling. A section of stove pipe was placed over the seedling during the spraying operation to protect it from the spray and possible ill effects. The mixture used was:  $\frac{3}{4}$  ounce simazine,

<sup>2</sup> John E. Krajicek. *Growing space requirements. In Black walnut culture. 94 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1966.*

2 ounces dalapon, ½ fluid ounce 2,4-D amine, 1 teaspoon of low-sudsing detergent, and 1 gallon of water.<sup>3</sup>

## SURVIVAL

In early September 1972 the survival count was about 93 percent. Only half the normal amount of rain fell during the growing season causing a severe drought and apparently an early leaf fall. It is believed that some persons making survival counts judged that seedlings that lost their leaves early were dead. In view of this, survival may have been even better than 93 percent.

## AGRICULTURAL CROPS

Although most owners of the Arkansas plantings used 40- by 40-foot spacings, one owner used 48 by 48 and another used 35 by 35 in order to clean-till crops intended for planting between the rows. Six of the 34 planters had planned to use clean-tilled crops — primarily soybeans. However, due to an early drought all but one of them left their land fallow. Most of the planters used the area between the trees for meadow. None pastured their orchards because the trees lacked protection against livestock.

In the 1972 and 1973 plantings about 10 percent of the owners will plant clean-tilled crops between the trees for several years and then will change these areas to meadow. The balance of the owners will use meadow for 9 or 10 years; about half of these will pasture their orchards. One owner is considering planting Christmas trees in his orchard. The trees immediately adjacent to the walnuts will be the first ones thinned.

## JUSTIFICATION FOR WIDE SPACING

Some consider the 40- by 40-foot spacing too wide. However, the following objectives are given to justify wide spacing:

1. Maximize diameter growth to obtain a fast-growing butt log 12 to 16 feet in length.
2. Maximize nut production by having large, spreading crowns.
3. Provide space between trees to grow an agricultural crop for income while awaiting log and nut production.
4. Obtain brush control by virtue of multiple cropping with agricultural crops.
5. Eliminate necessity of precommercial thinning as with closely spaced trees.
6. Reduce the rotation age and thus reduce the compound interest of the carrying charges for planting and improvement.

The above objectives more or less follow the premises made by Wylie that wide-spaced, short-boled, wide-crowned walnut trees produce greater nut crops and have faster diameter growth than closely spaced trees.<sup>4</sup>

Although it is too early to evaluate multiple cropping and wide spacing from our 1972 Arkansas experience, our planting techniques seem to have assured good survival despite the unusually dry growing season.

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<sup>3</sup> See page 114.

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<sup>4</sup> John E. Wylie. *Nuts and wood — dual crops for management*. In *Black walnut culture*. 94 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1966.

# VEGETATION MANAGEMENT INCREASES PRODUCTION IN NUT ORCHARD

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and

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**ABSTRACT.**— Tree growth, nut production, nut weight, and nut size were substantially increased by controlling vegetation with herbicides. The response to varying degrees of vegetation control has been consistent for the first 2 years of the study. Because of the magnitude of response, controlling vegetation appears to be a cost of orchard management that will prove profitable over the long run.

Considerable research has been done on the control of mixed hardwood species in new black walnut (*Juglans nigra* L.) plantations. In contrast, the study reported here was made to learn the impact of grass control on the tree growth and nut characteristics of established, nut-bearing trees. The study was started in 1971.<sup>1</sup> Results after two growing seasons are reported.

## METHODS AND MATERIALS

The walnut plantation studied is located near Vaughn, Arkansas, in the northwest corner of the State. It was established in 1963 and replanted in the following years until a uniform plantation with a 50- by 50-foot spacing was obtained. The plantation trees are Thomas variety grafted to native black walnut rootstock. The seedlings were grafted at age three and held in the nursery until age five. The first substantial nut production occurred in 1970.

The soil is a Razort gravelly silt loam, moderately fertile, alluvial, derived from limestone, and containing 15 to 35 percent chert gravel. The test trees are located in a field of perennial fescue (*Festuca* sp.) which yields one to two cuttings of hay or about 80 to 100 bales per acre per cutting. The soil is tested annually and fertilized according to recommendations for the fescue grass.

Twenty-five trees were selected for study. Five trees were assigned systematically to each of five treatments. Each tree was at the center of an 8- by 8-foot plot. The treatments were (1) diuron, (2) simazine, (3) terbacil, (4) total vegetation control, and (5) no vegetation control (check). The three herbicides were all applied at the rate of 3 pounds active material per acre. Only one application of herbicide was made each year accompanied by 1 pound of paraquat per acre. Total vegetation control was achieved by applying paraquat, 1 pound per 100 gallons of water, at monthly intervals with a garden sprayer. The check plots received no treatment. Herbicides were applied with a portable plot sprayer to assure accurate amounts.

Treatments began May 3, 1971; retreatment at the same rate was made April 17, 1972. The herbicides were selected to create a spectrum of vegetation control for evaluation of its effect on the trees. The percent of vegetation control was subjectively estimated at monthly intervals from initial treatment to September. An addition to the treatment series was made in 1972. On July 20, all the terbacil, simazine, and diuron plots were re-sprayed with 2,4,5-T amine, 4 pounds per 100 gallons of water, with a garden sprayer for broadleaf control. Blackberries and poison ivy were becoming particularly noticeable in some of the plots.

Both limb length and trunk diameter were measured as indices of growth response. After leaf abscission, a "best" accessible limb, one season's growth, was measured on each tree. Beginning in 1972, the tree's diameter growth was measured at a permanently marked

<sup>1</sup>H. A. Holt and J. E. Voeller. *Effect of vegetation control on established black walnuts*. *Ark. Farm Res.* 1(1): 8. 1972.

point on each tree at about 2 feet from the ground. Because of the low branching present in the trees, this height was used rather than diameter at breast height. The first measurement was made in April at the time of treatment and the final measurement after leaf abscission in November.

In October of each year the nuts were collected and immediately hulled. The fresh weight yield (for which the individual is paid) was measured for each tree. Each year, up to 10 nuts from each tree were oven-dried, measured for size, and cracked for kernel yield. In 1971, volume was estimated by measuring diameters of the nuts; in 1972, nut volume was determined by water displacement. The oven-dry weights of each nut and the kernel weight after cracking were measured for determining percent kernel yield.

## RESULTS

The results of vegetation control in 1972 agree with the 1971 results. Although the actual numbers change, the trends are consistent. The greater the vegetation control the greater the limb length (table 1). Limb length on trees having no vegetation (total "control") was more than 300 percent over the limb length on check trees. Even the limb length of trees with the least vegetation control exceeded the limb length of check trees by more than 180 percent.

Table 1.—*Influence of vegetation control on limb length and trunk diameter, 1972*

Treatment	Average	Growth	
	vegetation	Limb	Trunk
	control	length	diameter
	Percent	Inches	Inches
Check	0	7.7	0.26
Simazine	40	21.7	.44
Diuron	42	21.2	.47
Terbacil	86	24.5	.50
Total control	100	32.3	.66

Diameter growth for 1972, as with limb growth, constantly increased with increasing vegetation control (table 1). The least degree of vegetation control yielded nearly a 70 percent increase in diameter growth. Diameter growth of trees with no vegetation exceeded diameter growth of check trees by more than 150 percent. Nearly all trees treated with herbicide grew more than the fastest growing check tree.

The number of nuts was greater in 1972 than in 1971 for all treatments. This is a result of a higher proportion of the trees bearing in 1972 which, in turn, may be a reflection of tree maturity. Nut sizes, fresh weight, and oven-dry weight were consistently less than in 1971; percent kernel yield was greater than in 1971. The smaller sizes may result partly from the different ways of determining volume, but may also reflect the extremely dry summer of 1972.

Except in one case, controlling vegetation with herbicides increased the numbers, sizes, and weight of nuts (table 2.) For trees growing in plots in which all vegetation was controlled, average nut sizes were 35 percent greater than on check plots. Even the least effective herbicide treatment resulted in a 19 percent increase in nut size. The various treatments increased fresh nut weight an average of 11 to 17 percent over the check trees.

## DISCUSSION

The increased tree growth and nut production measured in this trial are perhaps attributable to several factors. The study trees are directly competing with fescue. There is evidence to suggest that grasses are more competitive, particularly for moisture, than other plant species. The field in which these trials are located is also fertilized annually after soil testing. Controlling the vegetation around the trees would tend to make both fertilizer and moisture more available to the trees. The summer drought common in this area may tend to increase response to available moisture. These factors are mentioned only to provide a context within which to interpret our results.

For the orchard owner, two items are of particular importance. One is the growth of the trees as related to vegetation control, which we have already discussed. The second, and perhaps the most important, is the nut yield during the productive life of the orchard. While there are some inconsistencies in the results, one factor is very obvious — vegetation control for the 2-year period increased nut production — both numbers and fresh weight (table 3). The untreated trees produced both fewer nuts and fewer pounds of nuts during both years than any of the vegetation control treatments.

Although the difference in nut numbers between the check trees and next best treatment was only 7 percent, the difference in pounds was a substantial 28 percent due to the larger size and weight of nuts. Obviously,

Table 2.—*Influence of vegetation control on selected nut characteristics, 1972*

Treatment	: Average : : vegetation : : control :	Total : nuts :	Nut : size :	Fresh : nut : weight :	Ovendry : nut : weight :	Kernel : yield :
	<u>Percent</u>	<u>No.</u>	<u>Cu. in.</u>	<u>Ounces</u>	<u>Ounces</u>	<u>Percent</u>
Check	0	716	1.12	0.75	0.54	27
Simazine	40	792	1.38	.88	.64	27
Diuron	42	495	1.46	.83	.68	27
Terbacil	86	1,602	1.33	.84	.62	28
Total control	100	929	1.52	.88	.69	25

Table 3.—*Cumulative nut yields per tree after 2 years of treatment*

Treatment	: Average : : nuts :	: Ave. fresh : : weight : : of nuts :
	<u>No.</u>	<u>Lbs.</u>
Check	151	7.14
Simazine	199	11.36
Diuron	162	9.12
Terbacil	337	19.06
Total control	208	11.69

his 28 percent increase is more important because nuts are sold by weight. Other comparisons, even more dramatic in nature, could be made; however, it is not the object of this report to recommend specific herbicides, rather only to point out the importance of controlling vegetation adjacent to the trees. The results are not particularly related to degree of control but do highlight the importance of vegetation control.

Our treated plots are only 0.0015 acre in size per tree; at the suggested spacing of 40 by 40 feet or 27 trees per acre, only 0.04 acre would be treated. The plot size used in this trial is not suggested as optimum but is just the size that we chose to treat. The treated area is a minuscule part of the total land area. Because of the small treated area per acre, the cost of herbicide per tree at the rates we used is only about 1 cent per tree. Assuming a minimal value of 4 cents per pound for the nuts, an increase in nut production of only one-fourth pound per year would pay for the herbicide. Our results indicate that the increased nut yield greatly exceeds that

amount. We would suggest that, even for this plantation just beginning nut production, the increases we have obtained would more than pay for the cost of material and cost of application. The increased growth of the trees and an increased future production is net profit.

The impact of the increased diameter growth also deserves some elaboration. Growth on the trees receiving total control indicates that veneer size walnut logs can be grown in half the time required by the check trees. The partial control treatments shorten the rotation age by more than a third of that required by the untreated trees. This has important ramifications not only for walnut grown in orchards but also for walnut grown in plantations for timber production.

A word of caution is also in order. Simazine and paraquat are the only herbicides in this study presently registered for use in nut-bearing walnut orchards. Terbacil and diuron were included to provide a spectrum of vegetation control for measuring plant response; this report *DOES NOT* recommend or suggest their use (see page 114).

Tree growth, nut production, nut weight (both fresh and ovendry), nut size, and percent kernels were all increased by vegetation management. Although this study is very limited in size, the data indicate very large and consistent responses to vegetation control over the 2 year period. Results in other areas, on different soils, or with different competing species, may be substantially different. We do feel, however, when operating under the multiple cropping concept with grasses as the competing species, vegetation control should be included in the total management program.

# BLUEGRASS SOD AND TREES

Jack Weeks, *Weeks Walnut Farm*  
*Pleasant Hill, Missouri*

**ABSTRACT.**—Profit was my motive when I planted 80 acres of black walnuts 11 years ago. Since then I have learned a great deal about walnuts and as yet have received no profit; however, I harvested 8,600 pounds of fine-quality nuts last year. I expect to start making a small profit in the next 2 or 3 years.

Using bluegrass as a second crop in the orchard has allowed me to receive a reasonable return on the land while the trees grow into bearing and will play a great part in the future profits from this operation.

When I first became interested in making a planting of black walnut I owned no farm or other land, so the first order of business was to acquire suitable land for an orchard.

At first I looked at the cheapest land available, and soon found that the reason it was cheap was because it was very poor land — mostly rough and unfit for walnuts or anything else. One tract of 120 acres I looked at was very good land — nearly all tillable — with 60 acres of good bluegrass pasture. It was priced at \$400 per acre. Since this was considerably more than I had expected to pay, I was not interested in this farm at first. However, the more I looked at hilly and eroded land — cut up with ditches and overgrown with brush — the more I thought about the good 120 acres at the higher price, and looking at that 60 acres of bluegrass I began to get an idea how I might be able to buy this farm. I contacted a landscaper and got a bid of \$225 per acre for the sod that could be harvested from this pasture. About 40 acres of it was salable.

I talked to several farmer friends about the feasibility of planting bluegrass for a sod crop. They were unanimous in their opinion that it couldn't be done — that it would take at least 5 years to produce a sod crop and the bluegrass would have to be planted with a nurse crop of alfalfa or clover. What they were doing was trying to tell me I couldn't do something I didn't know anything about; this was just the challenge I needed, so I bought the farm and immediately started to prove them wrong.

I planted 80 acres of walnut trees and started harvesting the grass that was salable and began to prepare the

remaining 60 acres of land for seeding bluegrass. Since I felt if you wanted to raise popcorn you wouldn't plant peanuts, I omitted the nurse crop and just planted bluegrass.

I was lucky with my first crop in that we had almost perfect weather and rainfall. In spite of much less than perfect planting we got a good stand of grass. The next year my mistakes began to catch up with me, and after making several mistakes that cost several thousands of dollars I became a very apt student of bluegrass culture. I am now happy to be able to say my methods and results have steadily improved over the years.

Ten years ago the bluegrass business was very much like the walnut business — you could get lots of advice from anyone you asked. The trick was to sort out the very small amount that was any good and would apply to my operation. I soon found that in the bluegrass business some specialized equipment was necessary. I built most of it myself or modified available equipment to do a special job.

In the beginning I was doing well to obtain a sod crop every 3 years from the same ground. Later I was able to step this up to every 2 years. In 1972 I harvested grass that was planted in the fall of 1971 — a 12-month crop; however, I feel that with timely rains a crop every 18 months will be about the best that can be expected on the average. As I improved my methods and produced a better grade of sod, the price went up. The first grass I sold brought \$225 per acre. The last I sold brought \$500 per acre.

While the selling price of turf has gone up, the cost of producing it has also increased. At first I was spending about \$75 to \$80 to produce an acre of turf. It now costs about \$160 per acre. The production costs have increased because of better seedbed preparation; using 40 pounds of seed per acre instead of 20, and using a great deal more fertilizer, more frequent mowing, and also spraying to control broadleaf weeds.

The net return using bluegrass as a second crop in my orchard is now about \$100 per acre per year. As long as this return remains at this level, I feel it is necessary to charge but a small amount of land investment to the trees and this will reflect in increased profits from the nut crop.

Because of my location — close to a market — bluegrass turf has proved to be a good choice for a second

crop with walnut. In fact, it has proved so profitable I have leased an additional 120 acres for production of turf. I now expect to sell about \$40,000 worth of turf each year. This causes me to whistle louder as I go to the bank.

There are other benefits from turf in an orchard. Both walnut and bluegrass respond well to high applications of nitrogen. With good turf underfoot, it is possible to get into the orchard with spray equipment in wet weather to better time the spray applications. The same applies to nut-picking time. You can move in on turf where otherwise wet ground might keep you out.

There are many problems with raising grass, but with good management they can be overcome, and a walnut orchard planted with bluegrass and kept well-mowed is one of the most pleasing sights you will ever see.

# FORAGE AND TREES

**Alan King, King Farms, Inc.**  
*Dadeville, Missouri*

**ABSTRACT.**—The use of walnut trees in a concept known as multiple cropping more fully utilizes the productivity of the land. Growing forage in the interim required for trees to mature seems to offer a logical use of medium- to high-cost cropland while sustaining trees as a secondary crop. The trees will gradually change from the secondary crop to the primary crop as they grow in size.

## MULTIPLE CROP CONCEPT

The idea of multiple crops is not new to many farms in this area. We at King Farms, Inc. have utilized the same acreage for pasturing livestock; growing small grain; and harvesting grass seed, legume seed, and hay — all in the same year.

The use of walnut trees as a part of a multiple-crop plan seems logical to us. Trees can be grown on a certain number of our acres being used for hay and pasture. We plan to be flexible as to whether the use in the early years will be pasture or hay.

We do know what income we can expect from the hay and pasture during the first few years, and the additional costs of maintaining the walnut trees will be primarily absorbed as extra time and labor of family members.

We feel these “extras” are important to making the overall operation a profitable one. We expect to continue the application of commercial fertilizer at the current cost of \$14 per acre per year or more, plus a limestone application every few years.

We have little experience in tree management but expect to be flexible enough in our future plans to adapt recommendations uncovered by research. We are confident the rate of walnut growth and production will be increased through research in the next few years and feel that the time to get started on a project of this type is now, instead of waiting to see for sure if it will work. A promise that it will work always breeds enough competition to lower the profit potential.

The use of land for cattle grazing requires careful management to realize a practical profit.

We must consider our ability to compete with other types of soil in walnut cropping. We know how to make comparisons of land productivity for growing grass through personal observation and actual research in terms of pounds of forage per acre, animal units per acre, or even pounds of beef per acre. In our operation the animal-unit method of comparison seems most reasonable because we deal primarily with breeding livestock, where sales cannot consistently be measured on a by-the-pound basis.

The land purchased at today's prices must produce more than natural grass in order to return even a small percentage on the investment. Taxes, maintenance, and overhead, all can be expected to increase.

The land where the 80 acres of walnuts are planted was part of a 500-acre tract purchased in about 1960 for \$74 per acre. The land was unimproved with a moderate amount of brush. Each 10 acres would support a cow-calf unit per year. A complete renovation, which cost approximately half the original land price, has increased the capacity to 3 acres per cow-calf unit. This capacity is made possible by \$14 per acre per year commercial fertilizer-lime costs.

We are planning to increase this cost as we have on other land to \$15 to \$18 per acre, which will enable us to carry the cow-calf unit on 2 to 2½ acres. Of course, this is all useless unless we concentrate on the cows' ability to calve and produce more beef per pound of forage.

The land today would cost at least \$350 per acre, which gives a cost per acre for interest alone of \$26. When we plug in a cow-calf unit investment of \$350 we must have \$36 per acre return for fixed overhead before we allocate cost to fertilizer, labor, machinery, etc.

Since the variables become so great at this point I prefer to show the growth of grass on our land as follows:

*Dollars per acre*

Interest on land (\$350/acre)	26
Annual fertilizer treatment	16
Taxes and Maintenance	<u>2</u>
Total expenses	44
Production of 5,000 lbs. forage at \$20/ton net	50
Optional returns fescue seed 300 lbs./acre at \$.80/lb. net	<u>24</u>
Total income	74

Normal production of forage, beef, or most any farm product is seldom highly profitable within itself. It is the options that make the success, such as the fescue seed crop. This is the reason we are seeking walnut trees as another "complementary option."

Cropping by today's methods usually requires efficient equipment and a definite plan or pattern. The owner who undertakes multiple cropping must select his site with his future cropping plans and machinery type in mind. A field that is undesirable for hay or row crops will be even less desirable after the planting of walnut trees. And farming around the trees seems to amplify the problems presented by obstacles such as stones, ditches, terraces, and irregular surfaces.

It is very easy to place the trees in the ground with decreasing accuracy as the hours of planting wear on; however, a few inches variance can become a great obstacle to a specialized piece of equipment over the period of years that the tree will be one of the crops.

Getting the most from the acre of land while practicing good conservation seems to be the name of the game. We plan to continue growing grass; the addition of trees should not lower the economic value of the grass until the trees themselves can begin to contribute to the income per acre of land. We do not consider the walnut plantings an economic gamble, but a conservation-type investment of "future faith."

# DISEASES

**Frederick H. Berry**, *Principal Plant Pathologist*  
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*Northeastern Forest Experiment Station*  
*Delaware, Ohio*

**ABSTRACT.**—Several diseases that can cause considerable damage to black walnut trees are discussed. Walnut root rots are serious in a number of nurseries where black walnuts are grown. Anthracnose is the most serious foliage disease of black walnut, and some methods for its control are suggested. Other diseases discussed include walnut bunch, heart rots, and cankers.

Black walnut is host to a large number of disease organisms. The "Index of Plant Diseases" (USDA 1960), lists more than 50 disorders of this tree species. Fortunately, most of these are not serious and cause little, if any, economic loss. There are, however, several diseases that walnut growers need to be aware of because on occasion they do cause considerable damage.

## ROOT ROTS

Root rots are the most widespread problem with black walnut nursery stock. They occur to some extent in almost all nurseries where black walnuts are grown. These root rots apparently can be caused by several different soil fungi.

A root rot caused by the fungus *Phytophthora citricola* has been responsible for serious losses at the Jasper-Pulaski State tree nursery in Indiana (Green and Pratt 1970). Initial infection occurs in the seedbeds, usually in spots or patches. The diseased walnut seedlings are killed in the seedbed, or infection may continue to develop in overwinter storage and cause losses in the spring during handling and shipping. The first visible symptom of the disease is a wilting of the more succulent parts of the tops, followed by blackening of the entire plant. Examination of these infected plants reveals that most of the roots are dead or dying, and water-soaked lesions usually are visible at the root collar (fig. 1). Soil moisture is critical for infection, and the disease is usually more severe after periods of heavy rain or high soil moisture levels.

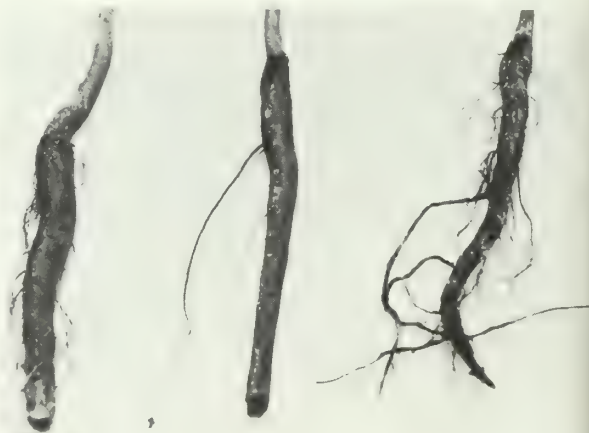


Figure 1 — Root rot of black walnut seedlings infected with *Phytophthora citricola*.

Other tree nurseries have reported a similar root rot of black walnut seedlings. *P. citricola* was also isolated from diseased walnut roots from the Green Springs State Nursery in Ohio,<sup>1</sup> and *P. cactorum* was isolated from walnut seedlings that suddenly wilted and died in a North Carolina nursery (Crandall and Hartley 1938).

Walnut seedlings at the Vallonia tree nursery in Indiana developed a stem and root condition similar to that described for *Phytophthora*. *Fusarium episphaeria* was isolated with regularity from the root portions of these seedlings.<sup>2</sup> The pathogenicity of this *Fusarium*

<sup>1</sup> Personal communication with Robert G. Linderman, September 21, 1972.

<sup>2</sup> Personal communication with Frederick M. Rothwell, August 30, 1972.

species was determined by artificially inoculating the fungus into roots of healthy walnut seedlings.

Soil fungi associated with walnut root rot in other nurseries include *Cylindrocarpon radiculicola*, *C. candidum*, *Pythium vexans*, and *Cylindrocladium* sp.

Fumigation of nursery seedbeds does not control walnut root rot since these soil-borne pathogens are often carried in from unfumigated areas.

Some degree of control can be attained by avoiding areas in seedbeds where the drainage is poor and surface water may stand. Methods of direct control by chemicals or other means need to be investigated.

The disease is considered an important limiting factor in production of black walnut nursery stock. And when seedlings with root rot are outplanted, they often do not survive.

## ANTHRACNOSE

The most serious foliage disease of black walnut is anthracnose, caused by the fungus *Gnomonia leptostyla*. This disease may quickly reach epidemic proportions during wet weather in the growing season and cause many walnuts — from seedlings to mature trees — to lose almost all their leaves by midsummer. This premature defoliation slows growth, weakens trees, and sometimes kills them. And the dark, shriveled kernels from diseased trees are usually not viable.

Black walnut trees vary in their susceptibility to walnut anthracnose. But during rainy seasons even the less susceptible trees become severely infected and defoliated.

Leaves, nuts, and occasionally shoots of the current season's growth are all attacked by the fungus. Tiny dark brown or black spots appear on infected leaves (fig. 2). Gradually these spots become more numerous, enlarge, and often merge to form still larger dead areas. Yellowish- to golden-leaf tissue usually borders these areas.

Sunken necrotic spots, smaller than those on the leaves, appear on husks of infected nuts. When immature nuts become diseased, they do not develop properly and many drop prematurely.



Figure 2. — Anthracnose lesions on a black walnut leaf. Causal agent is *Gnomonia leptostyla*.

No practical control of anthracnose is known for walnut trees growing under forest conditions. In nurseries, control of the disease can be accomplished by periodic spraying of the walnut seedlings with fungicides. Zineb and maneb have given satisfactory control at the rate of 2 pounds per 100 gallons of water.<sup>3</sup> To protect the seedlings it is necessary to apply the first spray when leaves are about one-half mature size, followed by two or three additional sprayings at bi-weekly intervals.

Recently, an experimental fungicide, triarimol, has shown promise of controlling walnut anthracnose in Ohio nursery beds.<sup>4</sup> Further studies are in progress to test its effectiveness.

<sup>3</sup> See page 114.

<sup>4</sup> Personal communication with Winand K. Hock, October 15, 1972.

## WALNUT BUNCH

This disease was once thought to be caused by a virus. However, recent studies have shown mycoplasma-like organisms regularly associated with diseased trees.<sup>5</sup> Mycoplasmas appear to be the smallest living organisms, somewhat larger than viruses, but smaller than bacteria. Though mycoplasmas have been known to cause disease in animals for many years, they have been discovered in plants only recently.

Bunch disease is known to be present throughout the eastern United States. Concern over possible spread of the disease to the West Coast resulted in California's placing a quarantine on the importation of walnut nursery stock from east of the Rocky Mountains.

Besides black walnut, bunch disease has been found on butternut, Japanese walnut, and Persian (English) walnut. Japanese walnut is most susceptible, and black walnut seems to be most resistant. Symptoms on black walnut are often so mild that diagnosis is difficult, and some trees may be symptomless carriers.

The most characteristic feature of bunch disease is the tendency of axillary buds to grow rather than to remain dormant. This growth produces tightly packed bunches of small wiry shoots and undersized leaves. The diseased shoots do not go into dormancy in the fall and are susceptible to cold injury.

The wood of diseased trees becomes very brittle, branches die back, and highly susceptible trees are often killed. Affected trees set few nuts and those that mature are usually soft-shelled and poorly developed.

Control of bunch disease is difficult because means of spread and method of infection are unknown. Removal of diseased branches from black walnut trees may be practical because this species seems to be less seriously affected than other walnut species, and diseased trees have been known to recover naturally. No infected trees should be allowed to remain in the vicinity of walnut nurseries.

## OTHER DISEASES

Several species of heart-rot fungi cause decay of the heartwood of black walnut. Two of the most common

heart-rotters are the "false tinder" fungus *Fomes igniarius* and the "sulphur fungus" *Polyporus sulphureus*. These fungi usually gain entry through wounds or dead branch stubs. No direct method of controlling heart rots is known. Initial infections can be kept at a minimum by maintaining tree vigor and preventing wounding.

Cankers on black walnut trees caused by the fungus *Nectria galligena* have a characteristic target appearance, resulting from a perennial killing of bark tissues by the fungus in the autumn and growth of host callus material in spring or early summer. Although few cankered trees are killed, the quality and quantity of lumber or veneer produced from them is often lowered. On good sites cankers tend to heal, while on poorer sites the rate of canker enlargement often surpasses the healing rate. All badly diseased trees should be felled and the cankered tissues cut out and burned.

A basal stem canker disease has been found recently in walnut plantations in Indiana, Illinois, and Missouri. Bark and cambial tissues are killed in the cankered area, which is just above the ground line. Eventually the canker encircles the stem, translocation of materials upward from the roots is interrupted, and the crown dies. Dead and dying trees are colonized by ambrosia beetles, and one of the first indications that a tree may be cankered is the appearance of tiny "pin holes" in the stem, from which insect frass is extruded. Research is in progress to determine the cause of the disease.

## RESEARCH NEEDS

There is a definite need for more research on diseases of black walnut. Many problems still need to be solved. For example, new environmentally acceptable control measures are urgently needed for walnut root rot. And as black walnut plantings increase, new disease problems will assuredly appear.

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<sup>5</sup> Personal communication with Carl E. Seliskar, March 28, 1972.

# INSECTS AS RELATED TO WOOD AND NUT PRODUCTION

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**ABSTRACT.**—The more important insects affecting wood and nut production are named and briefly discussed. Wood crop insects mar tree form or impair incremental growth by retarding or spoiling it. Walnut production practices may at times unintentionally increase insect numbers. Nonchemical control or regulation measures are highlighted. New information about insects is not keeping pace with progress in other aspects of walnut production technology.

Little new knowledge about black walnut insects has accumulated in the 7 years since the report by Hay and Donley (1966) at the Walnut Workshop. My presentation mainly exploits old information and allied experience outside walnut culture. Neglect of protection research may prove costly by slowing progress toward ideal production technology.

Walnut protection can be divided into the following categories, which are listed in descending order of existing knowledge: (1) developing nut crops, (2) developing wood crops, (3) nuts in storage, and (4) developing nursery stock. While convenient, these categories do overlap somewhat. For example, some insects that reduce nut production also reduce wood increment; some that feed in developing nuts continue feeding after nuts are stored.

The first two categories will be elaborated here; the last two will be omitted because there is too little knowledge for a meaningful discussion about insects that attack nuts in storage or developing nursery stock.

Measures for direct insect control or direct regulation will be detailed here only when nonchemical in mode of operation. Pesticides are subject to rapid improvement and change in official registration. Local extension representatives should be consulted for current recommendations. Several measures for regulating insects indirectly by warding them off instead of killing them will be noted. Though overshadowed by pesticide technology, these indirect measures suggest that more could be developed.

## DEVELOPING NUT CROPS

Walnuts, like other seeds, are an energy-rich food source for insects as well as humans. More information

is available about Persian walnut insects in the West than about black walnut insects in the East. A few insects affect both. The main ones now associated with nut crops of black walnut are:

1. Curculio or weevil (*Conotrachelus retentus*). Adults feed and lay eggs in immature nuts. Larval offspring then consume nut contents. The life cycle normally lasts 1 year (univoltine) (Schoof 1942). Foliage sprays applied after pollination are said to regulate the weevil. Nonchemical regulation is also possible in isolated plantings by promptly destroying nuts that drop prematurely. Such nuts contain a new weevil brood (Johnson 1969).

2. Husk fly (*Rhagoletis suavis*). The larvae or maggots can cause discoloration and off-taste of nut meats. Quality rather than production is affected. The insect can be regulated with foliage sprays containing contact or systemic pesticides with or without attractants (Nickel and Wong 1966, Johnson 1969).<sup>1</sup> The life cycle is univoltine. Because time of adult appearance varies, fly trapping is important for scheduling pesticide applications. The design and use of a simple fly trap are explained by Johnson (1969). Husk fly damage may be lessened nonchemically if late-maturing walnut varieties are cultured because the flies cannot successfully lay eggs when husks are hard (Johnson 1969).

Mites, aphids, and foliage-eaters may reduce nut production when their populations become high (Michelbacher and Ortega 1958). Since their feeding also reduces wood increment, these arthropods will be discussed in the wood crop category.

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<sup>1</sup> See page 114.

Insect-caused nut losses have not been deliberately searched out nor scientifically evaluated. Awareness of the above nut feeders is due mostly to capsulized grower experience. Nut-life tables derived from systematic observations of crop development from pollination onward could reveal overlooked or over-rated insect problems (Harcourt 1970). In the only study approaching this type I know of, 205 immature nuts on five black walnut trees in an Illinois orchard were tagged and their survival recorded.<sup>2</sup> Seventy percent of the tagged nuts never reached maturity. Their fate is unknown but insect intervention was likely. Close study of developing seed crops almost always implicates insects as a bibliography like Barcia and Merkel (1972) reveals.

Decisions whether to regulate insects that directly affect nut production will depend on whether the objective is to maximize nut production, stem volume, or a dual crop. Short logs and long crowns are recommended in dual-crop culture in contrast to wood production alone; large crowns produce more nuts and larger stem increments (Wylie 1966). Nevertheless, regulation of nut feeders increases nut biomass at the expense of other tree increments, including that of the stem. Reductions in radial stem increment and other vegetative growth accompany years of intense reproductive growth in many tree species (Matthews 1963). Current-year biomass distribution among black walnut tree parts remains to be fully examined, but tentative estimates are available from the work of Schneider (1970). Schneider measured biomass of different aboveground parts of 31-year-old black walnut trees. When converted to current-year values (for stems, dividing total stem biomass by years of tree age), the additions to stem and nuts amounted to about 20 and 4 percent, respectively, of total current biomass accumulation. Schneider termed the year of his observations a light nut year. In a heavier nut year, nut crop and stem-increment biomass may be more nearly equal. These relationships need elucidation to facilitate decisionmaking about nut insect regulation and wood-production trade-off.

Intensity of insect infestation in nut crops of black walnut varies inversely with crop size (Johnson 1969). This phenomenon occurs in orchards of all kinds where fruiting is sporadic. In pine seed orchards, mathematical analysis showed more precisely than previously known how insect-caused loss is related to variability in crop

size (Mattson 1971). This analysis revealed that conditions which stabilize and increase seed production lead to greater insect-caused losses. At the same time, the interaction between fluctuating seed crops and insects suggests that manipulating crop size offers a potential means of regulating insects.

## DEVELOPING WOOD CROPS

This is perhaps the most complex protection category because it involves a long growth period during which quality is very sensitive to cambial and wood injury by insects. As every log buyer knows, the quality of black walnut growing-stock inventory continues to dwindle. The most recent survey figures (Quigley and Lindmark 1967) show that only 15 percent of sawtimber volume is log grade 1, which includes veneer. Just how much insects contributed to this poor quality can only be guessed, but the present inventory represents growth essentially without protection from biotic agents. Baker (1972) discusses more than 50 kinds of insects that feed on forest black walnut. His treatise is useful but unstructured for black walnut wood production purposes.

Goal-setting speeds technological progress by molding and focusing problem-solving efforts. The black walnut wood production goal is instructive for protection purposes. The guiding product is the veneer log, which exceeds standards for log grade 1 (Freeman 1966) and is worth several times more money. Minimum dimensions of veneer logs are not standard, but many people might agree on 9 feet for length and 15 inches for top diameter. Such logs must be free of all defects, including insect holes (Clark 1969). The implications for protection are these: The first 9 to 17 feet of stem should grow uninterrupted and straight, the exact distance depending on length of log desired. This phase of height growth encompasses 5 to 10 years on most sites (Carmear 1970). After form-phase growth, annual radial increments should be maximized and maintained without blemishes to harvest. This incremental phase of growth encompasses 30 or more years (Clark 1969).

## Form-Phase Insects

Insects in this group eat or otherwise injure terminal or elongating shoots. Apical dominance is tenuous in black walnut and disruptions are easily induced. When a leader bud or shoot dies, takeover by a lateral usually results in stem deformation. Shoot injuries of unclear origin, such as those mentioned by Moore (1967) and Ashworth (1969), are probably partly due to insects. More investigation will doubtless swell the following list of form-phase insects:

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<sup>2</sup> *Personal correspondence with R. E. Phares, 1972. Data on file at the North Cent. For. Exp. Stn., St. Paul, Minn.*

1. Shoot moth (*Gwendolina concitatricana*). Only recently identified as a black walnut feeder, this insect occurs widely. In the only published report of its feeding, larvae killed 50 percent of the terminal buds of seedling sprouts in a Kansas stand (Naughton 1970). Its life cycle remains virtually unstudied. No regulation methods are known.

2. Case moths (*Acrobasis caryvorella* and *A. juglandis*). The larvae feed on buds, shoots, and leaves of black walnut and related trees. They build distinctive cases of silk and excrement. *Acrobasis caryvorella* produces from two to four generations a year (multivoltine) depending on latitude; *A. juglandis* is univoltine (Neunzig 1972). A related insect, *A. demotella*, feeds only on leaf petioles. Regulation measures based on pesticides have been developed for *A. caryvorella* (Phillips *et al.* 1964) and *A. juglandis* (Osburn *et al.* 1966) on pecan.

3. Curculio or weevil (*Conotrachelus retentus* and *C. juglandis*). Adults feed on terminals and leaf petioles before moving to nuts. Feeding signs are inconspicuous and may account for some unexplained deaths of buds. Adults lay eggs in some shoots, which are then mined by issuing larvae (Schoof 1942). Shoot infestations resemble frost injury (Renlund 1972).

4. Periodical cicadas (*Magicicada* spp.). Periodical cicadas include six allied species. Adults injure shoots and twigs by cutting egg niches. These heal slowly, kill some shoots, and increase breakage. In a given locality, periodical cicadas usually appear only at long intervals (17 or 13 years depending on latitude). Thus, form-phase black walnuts are not likely to be exposed more than once if at all. Small trees can be protected when cicadas appear by covering them with cloth, such as heavy cheesecloth or netting. Covers should remain in place for about 5 weeks. Cicadas can also be regulated with pesticides (U.S. Dep. Agric. 1971).

An accidentally imported ambrosia beetle, *Xylosandrus germanus*, was recently recovered in association with an unexplained dieback of black walnut saplings. Ambrosia beetles are normally nonaggressive feeders, but *Xylosandrus germanus* may not be typical (Heidenreich 1964). Its presence in two black walnut plantings in Indiana and Illinois represents two records; first occurrence on walnut and first appearance so far west (Bright 1968). Little is known about this Eurasian beetle in North America and it should be watched.

Although costly in labor and crop delay, shaping and coppicing are the best answers at present for insect-caused disruptions in form-phase growth. A practical guide for shaping is available (Krajicek and Bey 1969).

## Increment-Phase Insects

This group comprises defoliators, sucking insects and mites, and borers. By the manner in which they affect wood production they can be subdivided into increment retarders and increment spoilers.

*Increment retarders.* — The most familiar insects of black walnut are in this subgroup. Heavy insect grazing on black walnut canopies may divert photosynthates and lessen biomass additions to stem and nut crops. The more important examples are:

1. Walnut caterpillar (*Datana integerrima*). This common leaf eater is uni- or multivoltine depending on latitude. Its tendency to late-season defoliation moderates its effect on trees. Major outbreaks are sporadic. Eggs are laid on leaves in the lower crown no higher than 18 feet from the ground. Larvae feed near eggs during the early part of their development. A nonchemical regulation measure is removing leaves or branches containing larvae or scorching them with a pole torch (Hixson 1941). Regulation by pesticides is also possible (Osburn *et al.* 1966). The pesticide-containing protective paint discussed by Shelton (1970) seems promising with long-lived pesticides but not short-lived ones.

2. Walnut aphids (*Monellia* spp. and others). Complex in life cycle, these insects suck sap and remove cell contents of leaves. Their sugary excretions, known as honeydew, build up on leaves, branches, stems, and ground beneath dense populations and support a sooty mold. Only chemical regulation measures are available (Johnson 1969). *Chromaphis juglandicola* was successfully regulated experimentally on Persian walnuts by injecting pesticide into trees (Heffernan 1967).

3. Spider mites (*Panonychus ulmi*, *Tetranychus urticae*, and others). These almost microscopic forms suck sap and remove cell contents of leaves. The above-named species are important in many kinds of crops. A grayish or bronze discoloration of leaves is a sign of dense and injurious populations. Only chemical regulation measures are available (Johnson 1969). More conspicuous but less damaging are microscopic nonspider mites of the eriophyid group. These cause leaf crinkling and velvety growths on leaves and shoots. The symptoms are well known (Johnson 1969), but mites I re-

covered from such growths in Illinois proved to be new to science.

4. Elm spanworm (*Ennomos subsignarius*). This widely distributed univoltine leaf eater feeds on a variety of trees but has a strong preference for black walnut. It can kill trees by persistent yearly defoliation. Only chemical regulation measures are available (Fedde 1971).

At least two dozen more insects could be mentioned (Baker 1972), and there may be some as yet undiscovered. There has been little search for insects feeding on black walnut roots, for example.

Increment-retarding insects exemplify the most pressing informational need concerning black walnut insects; namely, scientific evaluation of impact potential. By its long duration, increment-phase growth complicates insect regulation. One problem is assuring a return on protection investments. Ferrell and Bentley (1969) considered economic aspects of black walnut wood production but they did not include insect-protection expenditures. Present levels of information about black walnut insects inadequately illuminate insect regulation alternatives.

Another complication is that trees can tolerate insect grazing on their leaves to an unknown degree without loss. Partial defoliation may not be detrimental because more light reaches leaves that normally would be shaded. Up to 50 percent removal of live crown caused no loss in stem increments in black walnut pruning experiments (Clark and Seidel 1961).

A more subtle complication is that cultural practices sometimes favor insect buildups. Stabilizing seed crops has already been mentioned as an example. Monoculture, in contrast to occasional individuals or small groups of black walnut in natural forests, is a cultural shift to which some insects will doubtless respond by increasing their numbers. Nitrogen fertilization appears to be promising in black walnut culture (Neely *et al.* 1970). Fertilizers and pesticides that are detrimental to some arthropods may stimulate others, notably sucking forms, by changing the physiological makeup of trees (Rodriguez 1960, Chaboussou 1965, and Stark 1965). The term trophobiosis was coined for such responses. Trophobiotic evidence comes from a wide range of crops, including at least one example from Persian walnut culture cited by Chaboussou (1965): the scale insect *Lecanium prunosum* increased three- to more than ten-fold following pesticide application.

*Increment spoilers.* — Insects in this group are borers. Typically, they infest trees that are stressed due to drought, defoliation, or other adverse factors. Black walnut is very sensitive to cambial disturbance; mechanical penetration may result in wounds much larger than the original hole (Clark 1966). Baker (1972) discusses more than 15 species of insects that bore in black walnut. The more aggressive forms are listed below:

1. Flatheaded apple tree borer (*Chrysobothris femorata*). Larvae of this normally univoltine beetle feed first beneath the bark and later bore into the wood. Trees can be protected by wrapping stems with high-grade wrapping paper or burlap (Fenton 1942). *Chrysobothris sexsignata* is a related species also occurring on black walnut.

2. American plum borer (*Euzophera semifuneralis*). Larvae of this moth bore in stems and large branches. No regulation measures are known.

3. White oak borer (*Goes tigrinus*). Larvae of this beetle occasionally infest black walnut, making holes up to 1 inch in diameter and 10 inches long. The life cycle requires 3 to 5 years depending on latitude. No regulation measures are known.

Two beetles that may belong in the list are *Agrilus otiosus* and *Pseudothyssanoes lecontei*. Very little is known about them beyond occasional association with black walnut.

Certain woodpeckers are attracted to borer-infested black walnut trees (McAtee 1911). They may increase the size of the holes already present when they remove insects. The yellow-bellied sapsucker (*Sphyrapicus varius varius*) feeds on black walnut also (McAtee 1911). It causes most of the defect in black walnut known as birdpeck. The sapsucker actually feeds on sap and stem tissues. Although truly insectivorous as well, it catches free-living insects rather than those boring in wood (Rushmore 1969).

Tree stress cannot now be gauged meaningfully enough for efficient application of borer regulation measures like stem wrapping. The broad correlation between borer infestation and tree stress suggests that irrigation during drought is a potential borer regulation measure.

## ACTION AT COMMUNITY LEVEL

In contrast to insect regulation measures that one owner may apply in one planting, some types of action:

benefit the broad community of owners and plantings. Border quarantine and research are notable examples; the relevance of three others to black walnut are briefly discussed below.

**Tree improvement.** — Named varieties of black walnut as well as tree improvement research reveal that traits important for nut and wood production vary genetically. Certain strains of black and Persian walnuts mature late, a trait that desynchronizes husk and husk fly development to the detriment of the insect (Johnson 1969, Somers 1968). Inherent susceptibility of black walnut to other insects might likewise vary. Too little is now known about black walnut insects for tree improvement purposes, however. As a result, feeding patterns by different insects in early performance studies of black walnut selections have been uninstrucively lumped (Bey 1970).

**Biological insect regulation.** — On Persian walnut in California, early results show promise for community-wide regulation of the aphid *Chromaphis juglandicola* with the imported parasitic wasp *Trioxys pallidus* (Van den Bosch *et al.* 1962). An installation for research in biological regulation of insects has been established by the USDA Agricultural Research Service at Columbia, Missouri. An opportunity also exists for exploring biological regulation of black walnut insects under foreign agricultural research provisions of Public Law 480 (Fowells 1970). For example, at least a dozen kinds of walnut insects are known in Himalayan Asia (Browne 1968, Janjua and Chaudhry 1964). Under Public Law 480, their parasites and predators could be searched out and evaluated for importation.

**Insect reporting services.** — Seasonal insect development, local insect movements or buildups, and other early warning information could be useful in walnut protection. In Illinois, the *Insect, Weed, and Plant Disease Survey Bulletin* is issued weekly from the latter part of March to August by the University of Illinois. Many other States assemble and distribute such information also.

## CONCLUSION

Some information has accumulated about insects as related to black walnut wood and nut production. New knowledge about insects is not keeping pace with progress in other aspects of black walnut production technology. Insect management cannot be developed in isolation because insects interact with other production factors. The most immediate need is rigorous impact

evaluation of known insects and closer scrutiny of developing crops for overlooked losses due to insects.

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# EVALUATING ECONOMIC MATURITY OF INDIVIDUAL TREES

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**ABSTRACT.**—The decision to cut a walnut tree should be carefully weighed in terms of its present value as opposed to its future value. Maximum economic yield is possible when each tree is evaluated as an individual in terms of its own quality, size, and growth rate. Instructions are given for the use of a graph to find the compound earning rate and examples show the effects of pruning and release.

Because of prevailing high stumpage prices for black walnut logs and veneer bolts, landowners are frequently faced with the question of whether to cut a particular tree now or allow it to continue to grow.

Foresters, in giving marketing advice to landowners in these situations, can usually spot individual trees which they know — by experience — should be cut or left on the basis of their apparent present value compared to their value as a “growing” investment. However, some of the thoughts which are behind these decisions on economic maturity are not easily explained. Economic decision processes provide an excellent way of showing the potential rate of return of individual trees.

The intent of this paper is to present a simple means of predicting future return for individual trees in relation to present size and rate of growth, using current average stumpage prices. The Doyle log rule was used for all volume calculations.

Stumpage values are principally influenced by tree location, quality, size, and mill price. If we assume that tree location and mill price are factors that the owner cannot change, then the only things the owner can do to increase his total return from a tree are those related to its quality and size at market time.

Reducing stand density and pruning greatly influence tree growth rate and quality. If a tree can be improved in grade or accelerated in growth, it increases in future market value.

Although dollar values are not the only factors to consider in deciding whether to cut a tree, it is desirable

to consider the future economic potential of a tree because it is a *measurable* factor for guiding the decision. Growth in value is influenced by the rate of volume growth and the premium price placed on large diameter logs. When the owner knows the minimum rate of return he is willing to accept, he has established his economic alternative rate — the point below which he will cut a particular tree and re-invest proceeds. He can predict the present earning (compound) rate for each tree evaluated (fig. 1).

## FINDING THE COMPOUND EARNING RATE

The compound earning rate is the annual rate of value increase over a period of years. To find the compound earning rate using figure 1:

1. First measure the tree d.b.h. (diameter breast high) to the nearest  $\frac{1}{10}$  inch.

2. Determine the grade of the butt log — prime, select, or common, according to the following definitions:

*Prime.* — Sound, straight, free of all defects.

*Select.* — Must have three clear (prime) faces; slight crook permitted if otherwise prime.

*Common.* — All logs (except cull) which are not select or higher.

3. Estimate the rate of growth as slow, medium, or fast according to the following definitions:

## Points to Remember

1. The graph shows only relative compound earning rates on basis of present value — not value in dollars.

2. Earning rates for select logs and prime logs are generally the same at any given d.b.h. and growth rate, because the stumpage values of select logs are a fixed percentage of the prime rate.

3. Whereas prime and select log prices go up in value per board foot with increased size, common log prices per foot are relatively fixed at all sizes.

4. Although 16-foot logs were used in the basic calculations, *relative earning rate* per log does not change appreciably as length is dropped to 12 feet, 10 feet, or 8 feet — only total value per log is affected.

5. Future changes in market prices (per board foot) will have no effect on the accuracy of these rate curves unless the relationship of value to log size and quality changes appreciably. Pricing factors that favor larger sizes and higher grades are built in.

6. Do not use this system on “high risk” trees or any other individuals where the decision to “cut or keep” can be made on some other appropriate basis. “High risk” trees are those that might not survive in the stand until the next harvest cut because of existing hazards.

7. Rates of return on “common” grades are applicable to *any* species sold on the Doyle Rule which does not have a premium price per unit on the basis of size or quality.

8. The rates of return were computed from tables listing values  $(1 + i)^n$  in tenths of a percent using the formula:

$$\frac{V_n}{V_o} = (1 + i)^n;$$

where  $V_n$  = value in  $n$  years  
 $V_o$  = value now  
 $i$  = compound rate  
 $n$  = years required per inch of d.b.h. growth

9. Average stumpage value for walnut trees can be computed by the following formula: Find a base minimum price for prime logs (30¢ per board foot in the

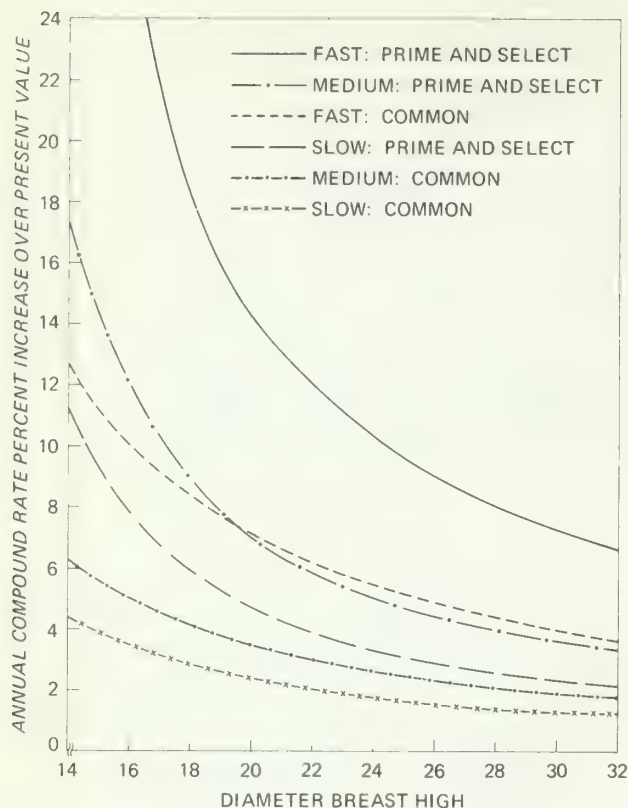


Figure 1. — *Spot evaluation of walnut trees — a guide for determining economic maturity of individual trees, F.C. 80 assumed. Plotted curves are at growth rate of: 4 rings per inch = fast; 8 rings per inch = medium; 12 rings per inch = slow.*

*Fast.* — Less than six rings per inch.

*Medium.* — Six to ten rings per inch.

*Slow.* — More than 10 rings per inch.

On the basis of site, growing space, and bark and crown characteristics, experienced foresters can place a tree in one of these three categories without the necessity of making increment borings. The landowner's personal knowledge of tree ages and growth rates can be used also.

4. Go to the bottom of figure 1 and find d.b.h.

5. Follow vertical d.b.h. line until it intersects with the proper growth and grade curve.

6. Follow horizontal line nearest this intersection to the vertical axis on the left to read off the compound earning rate.

example). For each inch of log diameter above the minimum (12 inches in this example), add 5¢ per board foot.

*Prime* per board foot =  $30¢ + 5 \text{ (d.i.b. - 12)}$ ; thus, a tree with the d.i.b. (diameter inside bark at small end) of 18 inches would be  $30¢ + 5(18 - 12) = 30¢ + 5(6) =$

$30¢ + 30¢ = 60¢$  per board foot.

*Select* =  $\frac{1}{2}$  the value of prime logs of the identical size.

*Common* per board foot = variable from 8¢ to 10¢ per board foot. There is no significant premium for common grade logs in larger diameter.

(Note: Market prices vary locally and seasonally, but tend to follow a pattern similar to that shown. The point here is to show the relative value.)

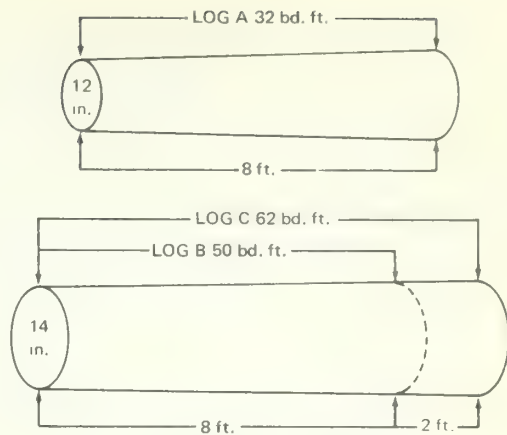
## Effects of Pruning and Release

Volume is affected by both the length *and* the diameter of the log. Increasing the d.i.b. without increasing the length of the log gives us a much slower *rate* of volume increase (fig. 2). Remember that diameter and length increases are both important and that clear length may be added by pruning the tree higher. Thus, pruning at the proper time can add significantly to total value of a particular tree. Using the stumpage values given earlier, a 16-inch log (prime grade) is worth: \$36 if 8 feet long, \$45 if 10 feet long, \$54 if 12 feet long.

It is obvious that, if it costs \$1 to prune a tree to the minimum 8-foot log, this dollar has the greatest rate of return if the log would have otherwise been common grade worth \$7.20. Value gained on the second and third prunings is much less significant but still worth the cost. The value as related to the cost of thinning and weeding can be estimated by use of the growth rate-earning rate curves. Release of pole-sized walnut from competition has yielded some rather dramatic increases in diameter growth rate.

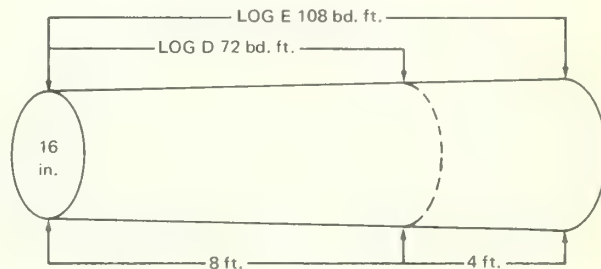
## EXAMPLE

A good quality walnut tree — potential prime log — 14 inches in d.b.h. — is found in a crowded young stand



Log B volume increases 56 percent over Log A.

Log C volume increases 94 percent over Log A.



Log D volume increases 44 percent over Log B.

Log E volume increases 74 percent over Log C.

Figure 2. — Schematic diagram to show how a 2-foot increase in log length together with a 2-inch increase in d.i.b. boosts volume considerably more than a 2-inch increase in d.i.b. alone.

of boxelder and ash. Current growth rate is eight rings per inch of diameter. After the tree is released from competition by clearing a 16-foot radius around the stem, it will accelerate to an average growth rate of four rings per inch. The rate of value increase per year jumps from 17 percent to over 24 percent (off the chart) (fig. 1).

If it costs \$5 to release the tree from competition, and the management objective is a 22-inch-d.b.h. by 16-foot veneer log: At eight rings per inch it would take 32 more years to bring the tree to market size. At four rings per inch it would take 18 more years (allowing 2 years for gradual growth response).

The potential market value is the same in either case, 196 board feet x 60¢ = \$117.60. This \$117.60 future sale value is worth less today than at the day of sale because of the discounted value of a future income — a reverse compound interest — comparable to what money you would have to put in the bank now to have \$117.60 at some future time.

If it costs you 6 percent interest to borrow money, then you must compute your investment rate at 6 percent. Thus:

\$117.60 discounted 18 years at 6 percent becomes

$$X = \frac{117.60}{(1 + .06)^{18}} = \frac{117.60}{2.85434} = \$41.20$$

now for the fast growing tree

but,

\$117.60 discounted 32 years at 6 percent becomes

$$X = \frac{117.60}{(1 + .06)^{32}} = \frac{117.60}{6.45339} = \$18.22$$

now for the slower growing tree.

The difference here of \$22.98 present value is the result of spending \$5 now to give the tree more growing space. The \$5 must be deducted from the \$22.98 gain shown, but still leaves a net gain of \$17.98 per tree treated in this way. If you had several such trees on 1 acre, the results could be spectacular.

# COST AND INCOME TREATMENT ON SMALL WOODLANDS

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**ABSTRACT.**—Universal demand and high value commonly associated with the sale of walnut timber may result in an excessive tax burden to farmer/woodland owners. It is the purpose of this report to present the proper treatment of incurred costs and the use, benefits, and regulations of long-term capital gains and losses as related to the small individual timber owner.

The sale of walnut timber, because of its universal demand and premium price, can result in an excessive tax burden to the small woodland owner if not handled properly. Quite often the sale of only a few large, high-quality trees can severely upset the farmer/woodland owner's estimated tax return. Unless the owner is familiar with the use, regulations, and benefits of long-term capital gain treatment of timber investments and the proper treatment of incurred costs, he may well forfeit his right to these benefits and pay more tax on the sale or harvest of timber than is legally due.

The sale of walnut timber is usually an infrequent event for the individual small woodland owner. Yet, a considerable volume of walnut timber is sold and harvested annually from such ownerships. Several hundred acres of black walnut plantations are established annually on small holdings. It is the purpose of this report to outline the treatment of costs incurred on small woodlands, and to interpret the regulations governing the treatment of forest income as long-term capital gain and loss. It is not necessarily within the scope of this report to cover all treatments for individual cases, but rather to interpret the tax regulations to guide the farmer/woodland owner in financial arrangements and decisions in managing costs and returns on the small woodland.

Although this report is primarily concerned with growing and harvesting walnut timber, its content in most cases may be applied to other timber crops.

## COST TREATMENT

Before dealing with forest income, the woodland owner should be acquainted with the treatment of necessary costs incurred while managing the timber crop. Most costs can be classified beneath the general headings of depletion, capital expenditures, and operating costs.

### Depletion

The investment cost of timber is recovered at the time of harvest through a tax deduction called "depletion." This deduction (depletion allowance) is determined by multiplying the volume of timber cut during the taxable year by the appropriate depletion rate. This rate is determined by dividing the total cruised volume immediately prior to harvest into the initial cost of the timber plus other proper additions to the investment cost (original cost and subsequent capitalized improvements) for the first sale. For all subsequent sales, the depletion rate is such that total depletion allowed to the remaining merchantable timber is equal to the remaining cost.

### Example

An owner bought a farm in 1950 for \$20,000; the farm supported 160,000 board feet of standing timber valued at \$2,000. In 1965, the same owner sold outright 50,000 board feet of timber for \$20 per thousand board feet, or \$1,000. By the date of sale, the stand had

increased 40,000 board feet due to growth, totaling 200,000 board feet. The depletion rate was found to be \$10 per thousand, or \$500, indicating a gain of \$500.

Original purchase	160 M bd. ft. at \$2,000
Growth	+ 40 M bd. ft.
Depletion basis	2,000
Total timber available for cutting	200 M bd. ft.
Depletion rate	
(\$2,000 ÷ 200 M bd.ft.)=	10
Depletion allowance	
(\$10 x 50 M bd. ft.) =	500
Total proceeds from sale	1,000
Less depletion allowance	- 500
Gain from sale	500
Depletion basis for future sales (\$2,000 less \$500) =	1,500

The depletion allowance is never computed from replacement cost, but rather from the investment cost. Depletion is formulated to recover capital investment costs of timber only; separate of land, physical plants, and equipment, though all were purchased in one unit. Therefore, when a tract of land supporting merchantable timber is purchased, it must be inventoried to establish the initial market value of the timber only, which is the investment cost of the timber. Gross income is reduced by the depletion allowance whether the income from timber harvests is fully taxed as ordinary income or taxed at a reduced rate under the provisions of capital gain and loss treatment. The depletion basis will need to be increased by the allocated value of additional timber purchases and by the amount of capitalized expenditures. Adjustments must also be made to reflect timber sales, casualty losses, and growth.

In the event that no depletion basis was established at the time timberland was purchased, that portion of the property which should have been allocated to timber will need to be known. If the purchase was cutover land or land supporting only immature timber, there will usually be no original depletion basis. If merchantable timber was present at the time of purchase, a forester should be consulted to establish its volume and fair market value. This information will establish the original depletion basis.

## Capital Expenditures

The treatment of incurred costs in growing plantation walnut or managing native walnut is sometimes a

problem to the small farmer/woodland owner. Some expenditures must be capitalized while others must be expensed. Capitalized expenditures cannot be deducted in the year incurred, but recovered through depletion or depreciation. Expensed costs may be deducted in the year incurred. It would be impractical to place all items of possible expenditure into a particular category, but some general guidelines can be drawn.

The Internal Revenue Service defines capital expenditures as "the amount paid or debt incurred for the acquisition, improvement, or restoration of an asset having a useful life of more than one year." These expenditures cannot be expensed, but may be recovered through depletion and/or depreciation allowances.

When land is purchased, the total purchase price (including costs for appraisal, land survey, recording fees, abstract search, and legal services) must be allocated to either timber, land, or buildings. This allocation must be proportional to the fair market values of each as of the date of purchase. From this allocation comes the investment cost of merchantable timber, which is only recoverable by depletion allowance at the time of sale or harvest. If no separate timber valuation was established when the farm or woodland was purchased, the proportional amount should be established. If no merchantable timber was on the property at the time of purchase, no allocation can be established for depletion.

The costs incurred in establishing a walnut plantation are considered to be capital expenditures. Site preparation for seeding and planting, cost of seed and seedlings and the cost of labor to plant or seed are all to be capitalized. These expenditures are considered to be the investment cost of the timber, and thus are only recoverable through depletion allowance at sale or harvest. Other costs which should be capitalized are fences, fertilizers, roads, bridges, firebreaks, and the cost of equipment with a useful life of more than 1 year.

## Operating Expenses

Operating expenses can be expensed. These expenditures are deductible from gross income as costs incurred during the taxable year as related to the production of income from timber stands. The individual farmer/woodland owner may expense ordinary and necessary expenses for the management, conservation, and maintenance of property held for the production of income. These costs include weed control, pruning, thinning of immature timber, cultivation, understory

brush control, short-life tools and minor equipment repairs, normal labor (excluding labor required to be capitalized), cutting and processing, materials and supplies, temporary roads, consulting fees, and other management costs. Deductible expenses are usually limited to costs for improvements having a useful life of less than one growing season. If the useful life of improvements cannot be determined, then these costs should be capitalized and recovered by depletion at the time of sale or harvest. If the useful life of such improvements is determinable for more than 1 year, the costs may be recovered through annual allowances for depreciation.

If the plantation or timber is in a preproductive stage, the land owner has the option of either expensing or capitalizing most normal operating expenses. This option would normally apply to taxes, interest, maintenance, fertilizer, controlling undergrowth, and cultivating and spraying trees. This option is mentioned as one method of treating costs incurred early in plantation establishment, though the individual farmer/woodland owner would seldom capitalize such expenses.

## Depreciation

The cost of property (tools, equipment, buildings, etc.) used in the trade or business or held for the production of income may not be expensed in the year of purchase. However, the owner is allowed to "deduct a reasonable allowance for the exhaustion, wear and tear, and obsolescence of such property as depreciation." The depreciation deduction, not unlike the depletion allowance, is never determined from replacement cost. Though several different methods are used in figuring depreciation, the basic concept is to allow annual deductions proportional to the life expectancy of the property with reference to its original cost.

## CAPITAL GAINS AND LOSSES

The Federal Internal Revenue Code provides for special tax treatment of gains and losses from sales or exchanges of capital assets. Such long-term capital gains or losses (assets held more than 6 months) are reduced by 50 percent before being taxed; and if total capital gains are less than \$50,000 (Tax Reform Act of 1969), the tax is further limited to a maximum of 25 percent of the long-term capital gain.

The maximum rate of 25 percent as interpreted in the Tax Reform Act of 1969 is available to individuals

for only the first \$50,000. Tax on the net long-term capital gain in excess of \$50,000 results in a maximum of 35 percent.

Capital gains and losses are given even more favored tax treatment in that the net long-term capital loss is deductible to the extent of the lesser of: (1) \$1,000, (2) the taxable income of the current year, figured without including capital gains or losses and without including personal exemptions, or (3) the excess of net short-term capital loss over the net long-term capital gain plus 50 percent of the excess net long-term capital loss over the net short-term capital gain. "Any capital loss not used in the current year because of the above limitation is permitted to be carried over to succeeding years."

Congress, in its attempt to promote continuous forest management, did apply certain basic ground rules in order for timber transactions to qualify for capital gains and losses — the timber or the cutting right to timber must in all cases be held in ownership more than 6 months prior to the beginning of the taxable year of sale. This requirement met, there are basically three approaches that may entitle the use of long-term capital gains treatment of woodland income: (1) infrequent transactions, (2) retained economic interest, and (3) cutting one's own timber to treat as a sale.

## Infrequent Sales

Whether infrequent sales qualify for ordinary or capital gain and loss treatment depends upon whether the timber is considered to be a capital asset. Commonly, if sales are so occasional as to be considered infrequent, and are unrelated to a trade or business in which the owner is engaged (not necessarily owner's principle occupation), the timber will qualify for treatment as a capital asset. The sale may include all timber, one or more species, or marked timber, but does not necessarily mean the liquidation of all timber. Timber sold must be sold for a lump sum. It must be sold outright, payment being a fixed amount agreed upon in advance. The important criterion here is that the woodland owner can sell his timber to a buyer and expect capital gains treatment unless the sale is "in the ordinary course of his trade or business."

Capital gains and losses resulting from infrequent, lump-sum sales are reported on Schedule D (Form 1040), Department of Treasury, Internal Revenue Service.

## Retained Economic Interest

Whatever problems are involved in applying capital gains treatment to the outright lump-sum sale are easily overcome by following the guides to transactions where economic interest is retained by the owner. Economic interest is usually retained where the owner is to be paid: (1) so much per cord, thousand board feet, or other convenient unit as stumpage is cut (pay-as-cut), (2) out of the production from stumpage disposed of, or (3) out of gross proceeds of sale of stumpage by the contractor.

When timber is sold where an economic interest is retained, ownership of the timber is retained until the trees are in fact cut by the purchaser. Title of the timber does not change hands until the tree is severed from its roots. The main criterion here is that the timber owner must rely upon the volume of timber cut to determine the compensation he will receive.

Two important advantages are apparent when timber is sold by contract with an economic interest retained. The Internal Revenue Service provides that timber is considered to be property in trade or business regardless of whether such timber is held primarily for sale to customers in the ordinary course of the owner's business. And, this type of sale also gives the owner more control over the timber sale.

Reporting gain or loss from the disposal of timber under these provisions facilitates paperwork in reporting taxes. Gains and losses are reported on Form 4797, Department of Treasury, Internal Revenue Service, along with other gains and losses the farmer may have sustained during the taxable year. The gain from the sale of timber is simply the difference between the gross sale price and the sum of depletion and other costs. Taxable gains and losses are then grouped with other sales, exchanges, or disposition of property held more than 6 months prior to the beginning of the taxable year that are a part of the normal farming business.

## Cutting One's Own Timber

If the farmer/woodland owner elects to treat the gain from timber he cuts as capital gains and losses (usually his advantage to do so), he must separate the value of the standing timber from the sale proceeds of resulting products. Capital gains are figured from the value of standing trees only; product price minus labor and transportation equals market value of standing timber.

This section of the Revenue Code applies to the timber owner who cuts his own timber for sale or for use in his business or trade.

Gain or loss from stumpage is computed as the difference between the fair market value on the first day of the taxable year and the depletion basis of the standing timber. This transaction may be treated as long-term capital gain or loss. The difference between the fair market value of the timber and the proceeds from the sale of resulting products, less costs, is in all cases treated as ordinary income.

If the timber owner elects to treat the timber he cuts for sale or use in his business, he must do so in subsequent years. Once the method is elected, it must be continued unless undue hardship can be shown and permission is obtained from the Internal Revenue Service to discontinue it.

The fair market value in this section must be established by the timber owner to the satisfaction of the Internal Revenue Service. The fair market value is considered to be the owner's cost in timber or the stumpage cost in a hypothetical sale by the owner to himself. Assistance in establishing this figure can be obtained upon request from the local extension, consulting, or farm forester.

In reporting gains and losses from this treatment, capital gains and losses are reported on Form 4797, which is similar to reporting income from contract sales where an economic interest was retained. The income from the sale of logs or converted products is treated as ordinary income. Farmers should report the gain on Form 1040, Schedule F, as other farm income. These gains would be reported on Schedule C by individual woodland owners, other than farmers.

## Other Sales and Receipts

Payment received from forest products other than standing timber is treated as ordinary income. Logs, lumber, gunstock blanks, fenceposts, firewood, chips, nuts, and bark are all reported as ordinary income. Income from such products would, in the case of the farmer, be reported on Schedule F, Form 1040. Similar receipts would be reported on Schedule C, Form 1040 for owners other than farmers.

Government payments for approved conservation programs must be included as gross income, whether

ceived in cash, materials, or services. The gross cost-sharing payment, actively or constructively received, reported on Schedule F, Form 1040. Since these payments are included as income, the expenditures for which payment was received must be treated as though no program was available. Total tree planting costs could continue to be capitalized and recovered through depletion at the time of sale or harvest.

Casualties and condemnations which may result in gains must be included as income. These gains, if held for more than 6 months and are considered capital assets, are reported on Part I, Form 4797, and treated as long-term capital gains. If the timber was not held for 6 months, it is reported in Part II, Form 4797.

Casualty, theft, and condemnation may in fact show a loss. In such cases, the loss may not exceed the depletion basis of the timber minus any salvage, insurance, or other compensations.

For further information in reporting gain and loss from timber transactions or in dealing with costs incurred, contact your local extension, farm, or consulting forester. Additional information may be found in U.S. Department of Agriculture Handbook No. 274, "The Timber Owner and His Federal Income Tax." A copy of this Handbook can be obtained for \$.50 by writing the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

# RETURNS FROM TWO SYSTEMS OF MULTICROPPING

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**ABSTRACT.**—An analysis was made of costs and returns from two hypothetical black walnut plantations of different spacings in which fescue was grown for seed between the rows of trees and nuts were sold. Fescue seed and nuts contributed a substantial share to total revenue. After allowance for all costs including income taxes, the internal rates of return were 8.3 and 12.9 percent respectively for the 18- by 18- and 40- by 40-foot spacings. Benefit-cost ratios were 1.39 and 1.67, based on a 6 percent discount rate. With the cost of land and initial costs of establishment assumed, \$15,000 to \$16,000 would be required to start a 40-acre plantation.

Interest in planting black walnut in Missouri is high — particularly because of the concepts of multiple cropping and the growing of superior trees from selected planting stock. Black walnut is unusual because substantial annual returns from nut harvests are possible at a relatively early age.

Genetically improved planting stock generally is not available, but at least a few investors have upgraded available nursery stock by using only the largest and most vigorous seedlings. If trees can be selected for desirable nut characteristics, such as large size and quality of nutmeat, annual revenues can be increased; rapidly growing trees can shorten the period to produce high-grade veneer logs.

Opportunities are being explored to grow agricultural crops, such as hay, orchard grass, or fescue for seed between rows of planted walnut trees. Cattle grazing appears promising if walnut trees can be protected from browsing and trampling. Agricultural crops and nut harvest bring early revenue to offset the initial cost of tree establishment.

What are the costs and returns from multiple cropping of black walnut? How much does the sale of nuts and other crops contribute to total returns? Is multiple cropping attractive as an investment? Plantations old enough to help quantify answers to such questions are not known. To explore multiple cropping investments, two hypothetical black walnut plantations were analyzed to provide an estimate of profitability. The data used are admittedly incomplete and somewhat speculative but are the best available.

## STAND DEVELOPMENT

For both alternatives, a 40-acre plantation was assumed, but the analysis was made for a unit of 1 acre. Land was purchased at a cost of \$200 per acre, including the amount paid and all costs of acquisition. If land were already owned, this amount would represent the opportunity cost of removing the land from other productive use. Part of the area, it was assumed, required clearing and terracing and the entire field was plowed and disced. Fertilizer was applied to eliminate nutrient deficiencies for fescue as indicated by soil testing. Because the enterprise was considered to be part of a full operation, a fence was installed on the exterior boundary to exclude livestock. The area was seeded to fescue in the fall and walnut trees were planted the following spring. Subsequently, fescue was eliminated from around each seedling by use of an herbicide. Elimination of competing vegetation was continued in the second and third years as recommended by Krajicek and Williams (1971).

Production of annual crops of fescue seed continued. Walnut trees were pruned in three stages to form stems, once at age 10 and again at ages 15 and 20.

For Case A it was assumed that walnut seedlings were planted at a spacing of 18 by 18 feet, 135 trees per acre. This spacing is relatively open compared to that used for conventional timber production. However, the trees were sufficiently close to reduce the yield of fescue, and the efficiency of combining and other equipment would be less than desired. Consequently

escue seed yield was assumed to be one-half that when grown under more open conditions.

The timber stand was managed in a traditional manner, with thinnings made at 5-year intervals, beginning at age 25. The volume removed varied from about 500 to 1,000 board feet (table 1). At age 80 the stand contained 7,100 board feet per acre and was harvested.

Nut production began at age 15 with 400 pounds per acre. The quantity harvested increased until age 35, then began to decline because the effect of tree removal by thinning more than offset increasing nut yield per tree. Nut yields were based on data derived from Naughton (1970). Although nut yields are shown as a uniform progression from year to year, it is recognized that actual nut yields may vary widely in an erratic manner. At least, the reasons are not apparent from examination of yield data.

Case B differs from Case A primarily because only 26 seedlings were planted per acre at a spacing of 40 by 40 feet and no thinning was necessary. A 40-foot strip at the edges of the field facilitated operation of farm equipment through the 80-year production period. Wider tree spacing permitted a larger area for growing escue so yields were double those for Case A. Because the trees in Case B are open-grown, nut yields were increased by 10 percent.

By age 80 the 26 trees, four more trees than for Case A, contained 8,400 board feet.

## COSTS

The cost of land was \$200 per acre. For a 40-acre field, 1 mile of fence was required. Recently constructed fences in central Missouri have cost \$1,800 to \$2,000 per mile; the \$2,000 rate was used. Initial costs for stand establishment were based on records for the Roubidoux Walnut Plantation, established in 1968 on the Clark National Forest. To provide for rising cost levels and greater precision required for this type of plantation, costs were doubled. The initial costs per acre for each walnut plantation are summarized:

	Case A	Case B
Land	\$200.00	\$200.00
Fertilizer	75.00	75.00
Fencing	50.00	50.00
Clearing and Site preparation	26.00	26.00
Planting stock	13.50	2.60
Sorting and trimming planting stock	4.10	0.80
Labor, supervision, transportation	16.75	11.30
Vegetation control, chemical and labor	5.40	1.05
Total	\$390.75	\$366.75

Table 1. — *Yield and stumpage value of timber cut and annual yield and value of nuts, per acre, in planted black walnut stand (Case A), site index 70<sup>1</sup>*

Age (years)	No. Trees	Mean diameter, inches	Volume cut <sup>2/</sup> , M bd. ft.	Stumpage price per M bd. ft., Dollars	Stumpage value of trees cut, Dollars	Annual yield <sup>3/</sup> , Pounds	Value of nuts <sup>4/</sup> , Dollars
10	135	4.9	--	--	--	--	--
15	135	6.8	--	--	--	392	20
20	135	8.3	--	--	--	1,336	67
25	135	10.0	0.15	97	15	1,958	98
30	120	11.9	.45	98	44	2,472	124
35	95	13.5	.62	104	64	2,508	125
40	74	15.2	.64	108	69	2,462	123
45	60	16.8	.68	352	239	2,280	114
50	50	18.4	.92	386	355	2,245	112
55	40	20.0	.98	525	514	2,100	105
60	32	21.6	.65	626	407	1,840	92
65	28	23.3	.40	750	300	1,750	88
70	26	24.9	.47	808	380	1,809	90
75	24	26.5	.54	1,530	826	1,843	92
80	22	28.1	7.10	1,655	11,750	1,841	92

<sup>1/</sup> Adapted from Naughton (1970). Figures rounded.

<sup>2/</sup> Volume of intermediate cut at age shown. Entire stand cut at age 80.

<sup>3/</sup> Average yield for age shown and previous 4 years.

<sup>4/</sup> Gross revenue at 5 cents per pound.

Vegetation control was repeated in the second and third years. The cost of pruning walnut stems was \$0.50 per tree, based on a study in Kansas by Clark (1953). This resulted in costs of \$67.50 for Case A and \$13.00 for Case B, each occurring three times. Annual costs consist of real property taxes, \$3.00 per acre and \$7.00 to cover items such as inspection, control of pests, and fence maintenance. The taxes, higher than present-day levels for farm land in Missouri, anticipate continued increases. Costs associated with growing fescue seed are accounted for under revenues, which are net.

## REVENUES

Grade yields of timber stumpage sold are those reported by Naughton (1970), which included grades designated prime, select, and common. Trees 10 to 12 inches in d.b.h. produced 25 percent select and 75 percent common. The percentage of select increased with tree size. Trees 17 inches in diameter included 20 percent prime, 25 percent select, and 55 percent common. The proportion of prime increased with tree size, and the harvest cut was distributed 50, 30, and 20 percent respectively for prime, select, and common.

Unit prices for stumpage also were adapted from Naughton (1970). For the purpose of assigning value, the diameter inside bark of the tree 17 feet above ground level was taken as the average log diameter of the tree. The resulting unit rates show that trees 10 to 15 inches in diameter were valued at about \$100 per M board feet (table 1). Because of higher quality associated with larger tree size, the stumpage value of trees cut increased rapidly from \$240 for 17-inch trees to \$380 for 25-inch trees. Larger trees contained substantially more veneer quality material and prices exceed \$1,500 per M board feet. These stumpage rates appear to be high, but if the demand for walnut logs continues, future prices may well equal or surpass these levels.

The cost of selling timber stumpage was set at \$5 per M board feet sold. It includes the costs of negotiating sales, contract preparation, and supervision. Income taxes are difficult to estimate without knowledge of a specific taxpayer's income, deductible items, and the applicable tax rate. However, an informal study of 30 timber stumpage sales indicated that the seller paid income taxes amounting to 15 percent of gross revenue. Revenue was reduced by selling costs and depletion allowances and the remainder was eligible for classification as a long-term capital gain. Accordingly income taxes were set at 15 percent of gross revenue.

Revenue from nuts under Case A is shown in table 1. Nut revenues for Case B were 10 percent higher, reflecting higher nut yields. These are based on a delivered price of 5 cents per pound. In the analysis, one-third was deducted to provide for the cost of collection and hauling (Whitney and Porterfield 1967). Net annual returns from sale of fescue seed were based on trials in southwest Missouri. For Case A the annual revenue was \$37.50 per acre and for Case B \$75.00. Whether these levels can be achieved and maintained is not known. Income taxes on revenue from nuts and fescue seed was set at 25 percent of the revenue.

## ANALYSIS

Criteria used for evaluation were discounted net worth (DNW), internal rate of return (IRR) and benefit-cost ratio (B/C). DNW results from discounting all cost and returns to the year in which the investment was undertaken at a selected rate of interest (discount). The larger the rate of discount, which is a measure of the value of elapsed time, the lower the DNW. IRR is the discount rate at which the sum of discounted costs equals the sum of discounted revenues; that is, DNW is zero. It is the prospective rate of return that the investment would earn when adjusted for time. The B/C ratio indicates the number of dollars of revenue that would be received for each dollar of cost incurred when these elements are discounted at a selected rate.

Using the costs and revenues previously described the results were determined. To save time, calculations were done by electronic computer utilizing the program RETURN, prepared by Schweitzer *et al.* (1967), and the results summarized (table 2).

Case B, open-grown walnut trees at a 40- by 40-foot spacing without thinning, appears to be a more attractive investment alternative. The DNW estimates at several rates of discount are higher for Case B. The DNW of \$618 computed at 6 percent, for example, may be interpreted to mean that the investment returned \$618 per acre in excess of a 6 percent return. Or, an additional \$618 could have been incurred initially and the rate of return would be 6 percent. For Case A, the DNW of minus \$122 indicates that the venture failed to earn 10 percent. If initial expenses, for example, could be reduced by \$122, a rate of 10 percent would be earned.

The IRR estimates require no arbitrary selection of a guiding rate of return. They indicate that if all quantities, prices, and other elements were to actually occur, Case A would earn an annual equivalent rate of return of 8.3

Table 2. — *Investment returns for two different spacings of walnut according to three criteria*

Case	Discounted net worth, percent				Internal rate of return	Benefit-cost ratio at 6 percent
	4	6	8	10		
	Dollars	Dollars	Dollars	Dollars	Percent	
Case A <sup>1/</sup>	1,376	378	29	-122	8.3	1.39
Case B <sup>2/</sup>	1,517	618	284	125	12.9	1.67

1/ Spacing 18 by 18 feet, 135 trees per acre.

2/ Spacing 40 by 40 feet, 26 trees per acre.

percent and Case B would earn 12.9 percent. The B/C ratios, based on a discount rate of 6 percent, indicate that Case A would return 1.39 dollars in revenue for each dollar of cost incurred and Case B would return 1.67. At higher rates of discount the B/C ratios would become progressively smaller and would reach 1.00 when computed at 8.3 percent for Case A and 12.9 percent for Case B.

When all revenues and all costs are summed for the 30-year period, they are not greatly different for Case A and for Case B, although the individual costs and revenues differ to some extent (table 3). When discounted at 6 percent, the annual incomes from nuts and fescue seed assume greater importance. It is significant that the timber revenues, which are received at the end of the production period, are extremely small in terms of present or discounted value. As to costs, initial investment and income taxes comprise a large share of the totals.

A potential investor would be interested in the size of initial investment required for a 40-acre plantation. For Case A the cost of land, site preparation, fertilizer, fencing, planting walnut, and sowing fescue would be approximately \$16,000. For Case B, because fewer trees were planted, the cost would be \$15,000.

## DISCUSSION

The contribution of annual or frequently occurring revenues has a large bearing on investment outcome. This indicates the desirability of planning a multiple-crop enterprise. The investor should take advantage of research and technology that will increase net revenues from nuts and interplanted farm crops. Initial investment and annually recurring expenses, if held as low as possible without detracting from yields, can materially increase net returns. If genetic research can develop faster-growing black walnut trees, shorter rotations will be possible, which should increase profitability.

Table 3. — *Total and discounted (6 percent) revenues and costs per acre for two different spacings of walnut over an 80-year period*

Item	Total				Discounted at 6 percent			
	Case A		Case B		Case A		Case B	
	Dollars	Percent	Dollars	Percent	Dollars	Percent	Dollars	Percent
Revenue:								
Fescue seed	3,000	13	6,000	26	619	47	1,238	80
Nuts	4,468	20	2,824	12	483	36	168	11
Timber	14,897	66	13,844	61	228	17	131	9
Return of land value	200	1	200	1	2	0*	2	0*
Total	22,565	100	22,868	100	1,332	100	1,539	100
Cost:								
Initial, including land	391	7	367	7	391	41	367	40
Annual expense	800	14	800	15	165	17	165	18
Income taxes	4,112	75	4,289	78	302	32	371	40
Pruning, weed control	214	4	19	0*	96	10	19	2
Total	5,517	100	5,475	100	954	100	922	100

1/ Spacing 18 by 18 feet, 135 trees per acre.

2/ Spacing 40 by 40 feet, 26 trees per acre.

\* Less than 0.5.

An analysis of this nature has a number of shortcomings. Adequately documented information on yields, costs, and returns usually is lacking so the "best" estimates available are used. Unforeseen losses may occur and catastrophic events happen all too frequently. Nevertheless, an investor should use all means possible to appraise a potential investment in black walnut.

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# INFORMATION AND SERVICES AVAILABLE TO THE LANDOWNER

**Burl S. Ashley**, *Field Representative*  
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*Forestry Sciences Laboratory, Southern Illinois University*  
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*and*

**John P. Slusher**, *Extension Forester*  
*School of Forestry, University of Missouri*  
*Columbia, Missouri*

**ABSTRACT.**—The efficient production and marketing of walnut products is dependent upon aid available to the grower. Many sources and kinds of aid exist including on-the-ground technical assistance, publications, seminars, and incentive payments. By carefully analyzing his needs and soliciting assistance from the proper source, each grower can better prepare himself for a successful walnut enterprise.

The subject of black walnut has received more attention within the last 10 years than ever before. Researchers have been delving into the "world of walnut" with increasing fervor which has unlocked many of the secrets to growing and utilizing this valuable species. In addition, landowners have become increasingly aware of the benefits derived from growing walnut and are seeking knowledge to make their growing and marketing operations more efficient and profitable.

Scientists are interested in getting their research applied. On the other hand, landowners desire to learn more about this research and put it into use. These two segments of the "walnut enterprise" must be closely associated if full success is to be achieved. There are many connecting links which, if properly used, will serve to fulfill the needs of numerous individuals involved with the growing and marketing of walnut products. These links include on-the-ground technical assistance, publications, seminars and other informational meetings, a multiplicity of sources for general information and incentives programs.

## ON-THE-GROUND TECHNICAL ASSISTANCE

The walnut grower who desires guidance with plantation establishment, insect and disease control, thinning,

pruning, or other aspects of management and marketing has various sources for these services.

All States within the commercial range of black walnut provide services, usually free, to private landowners who have forestry problems, such as the growing and marketing of walnut trees. These services are provided under the Cooperative Forest Management (CFM) Act of 1950, the legal basis for a cooperative effort between the USDA Forest Service and the State forestry organization. Upon request, arrangements can be made for a visit from a State-employed forester who will give professional guidance to the landowner. These foresters are referred to by various titles in different States. For example, in Missouri they are called farm foresters, in Illinois they are called district foresters, and in Indiana they are called service foresters. These men can be located by contacting any local government agriculture office or the State forester who is usually located in the State's capital city. These foresters provide advice about most aspects of producing walnut products from planting to the marketing and utilization of the final product.

Often a landowner desires to grow walnut but prefers not to do it himself. In such cases he will need a competent individual to manage the enterprise for him. A consulting forester can be the answer. These foresters

are self-employed and offer their professional services to the public for a fee. Though consulting foresters are relatively few in number, State forestry employees know where they may be easily contacted by landowners. Consulting foresters perform most of the same services as the State-employed foresters, but also offer additional assistance. For instance, in the case of plantation establishment, the State-employed forester prepares a plan, whereas the consulting forester not only prepares a plan, but carries it out. In the field of marketing, the consulting forester will carry out the entire sales operation while his State-employed counterpart is usually limited to tree selection and marking, supplying a list of buyers, assisting with the preparation of a contract, and other general duties.

Since soil conditions are critically important in a walnut-growing enterprise, a grower should always have an analysis made of the site. Some data may be obtained by the inspecting forester or by submitting soil samples to the local Cooperative Extension Service Office. However, a more detailed analysis is provided through the local soil and water conservation districts cooperating with the Soil Conservation Service of the U.S. Department of Agriculture. They usually have an office in each county. A visit or call to one of these offices will provide information concerning the availability of a soils analysis. Some soil and water conservation districts also offer tree planting services. All districts make recommendations regarding erosion control and conservation measures needed for each soil type involved.

Some private nurseries offer plantation establishment services including site preparation, planting stock, planting, and weed control. These nurseries are limited in number; however, they can be located by contacting a local forester.

## PUBLICATIONS

Regardless of the amount of professional services the landowner secures, it is important that he brief himself regarding walnut. Much of this familiarization should be done while he is contemplating his walnut management activities and certainly he should keep himself up to date as he proceeds with the work. An excellent approach to building a broad comprehensive background of knowledge on the subject is to secure good publications. These publications are available from several sources. Since it is impossible to list all

of them, only the principal sources are contained in the following list:

### 1. *Cooperative Extension Service.*

a. Local offices — usually one in each county (normally at the county seat).

b. Extension forester — located at the State university.

### 2. *State Forestry Division.*

a. Local offices — check at agriculture office for location.

b. State forester at headquarters office.

3. *Soil Conservation Service.* Most counties have an office located at the county seat.

4. *United Hardwood Forestry Program*, Attention Mr. Larry Frye, Columbia City, Indiana.

5. *North Central Forest Experiment Station*, USDA Forest Service, Folwell Avenue, St. Paul, Minnesota 55101, or Forestry Sciences Laboratory, Southern Illinois University, Carbondale, Illinois 62901. A bibliography of many walnut publications is also available from this source.

6. *State and Private Forestry*, USDA Forest Service, 6816 Market Street, Upper Darby, Pennsylvania 19082, or Forestry Sciences Laboratory, Southern Illinois University, Carbondale, Illinois 62901.

## SEMINARS

Since the demand for information on walnut has increased, there not only has been an influx of increased services and publications, but several walnut seminars have been conducted to augment these other sources of assistance. Basically, these seminars are of two kinds: one type is for professional foresters organized by State forestry divisions or the Cooperative Extension Service, and the other is designed for the general public organized by the Cooperative Extension Service. Several seminars have been sponsored by the walnut industries. Those presenting information have included walnut growers, the Cooperative Extension Service, USDA Forest Service, Soil Conservation Service, State forestry organizations, universities, walnut industries, and others.

Seminars are not presented at any prescribed interval but only when there is sufficient demand within a geographic area and the sponsoring agency considers it feasible. Landowners may request such seminars through local Cooperative Extension Offices, local foresters, or by contacting the State offices mentioned in the preceding paragraphs.

## ADDITIONAL SOURCES OF INFORMATION

Many sources provide valuable information, even though their primary function is not assisting walnut growers. In some instances these sources have information on specific subjects which is of value. Following is a partial list of these sources:

1. *Walnut Council*, USDA Forest Service, Forestry Sciences Laboratory, Southern Illinois University, Carbondale, Illinois 62901. This organization will refer requests for assistance or information to a competent source. Members are periodically informed of the latest developments concerning walnut.

2. *Northern Nutgrowers Association*, 4518 Holston Mills Road, Knoxville, Tennessee 37914. Members are kept informed about the production of nuts.

3. *Local or State Nutgrowers Associations*. Several States have such associations. The State offices of the various service organizations can usually advise as to the availability of local nutgrowers associations. Information is available to members through meetings and newsletters.

4. *Fine Hardwoods - American Walnut Association*, 666 North Shore Drive, Chicago, Illinois 60611. Requests for information regarding walnut will be referred to an appropriate source of assistance.

5. *Wood-Using Industries*. Many large veneer log and saw log industries are willing to give information

to a grower or advise him of where he can secure assistance.

6. *American Forestry Institute*, 1619 Massachusetts Avenue, NW, Washington, D.C. 20036. This organization occasionally prepares information on walnut and gives assistance and support to walnut programs. It sponsors the American Tree Farm System and welcomes walnut growers to participate in this program and receive recognition for their contribution to forestry.

7. *Nut-Using Industries*. Information is offered concerning the marketing of nuts. In addition, they sometimes have programs involving the growing of nuts and are willing to offer assistance.

8. *Other Growers*. Valuable information and assistance are available from other experienced walnut growers.

## INCENTIVE PAYMENTS

The Rural Environmental Assistance Program (REAP), which is administered by the Agricultural Conservation and Stabilization Service (ASCS), provides incentive payments for approved walnut plantings and cultural practices. The payments are usually 75 to 80 percent of the overall cost. This U.S. Department of Agriculture program is financed with a limited amount of funds in each county. Because these funds are divided among many agricultural practices, the amount available for forestry purposes is small. Approval must be received before a project is initiated. If a walnut grower is interested in the REAP, he should contact the ASCS office in the county where he will perform the practice.

## PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key — out of the reach of children and animals — and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.



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# FOREST SOILS BIBLIOGRAPHY FOR THE NORTH-CENTRAL REGION (Including Subject Matter Index Through 1972)



Willard H. Carmean



NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

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(Maintained in cooperation with the University of Minnesota)

# **FOREST SOILS BIBLIOGRAPHY FOR THE NORTH-CENTRAL REGION (Including Subject Matter Index Through 1972)**

**Willard H. Carmean**

## **FOREWORD**

This bibliography includes forest soils literature for the North-Central States (Minnesota, Wisconsin, Michigan, Iowa, Missouri, Illinois, and Indiana); Ohio; and the Northern Plains States (Kansas, Nebraska, and the Dakotas). Publications from other regions were included when applicable to conditions in the North-Central Region.

This is a large region covering many diverse soil, topographic, climatic, and vegetal conditions. The field of forest soils also is diverse, and thus forest soils literature for this region has become varied and voluminous. We hope this bibliography will not only be a helpful reference, but also perhaps will partially reveal the present level of forest soils knowledge for the North-Central Region.

The bibliography was begun by the Forest Soils Committee of the North Central Regional Work Planning Conference of the National Cooperative Soil Survey. The author extends his thanks to the many committee members who reviewed the bibliography and who provided citations for their particular States. Appreciation also is extended to the many other University, State, and Federal soil scientists who provided citations and helpful suggestions.

The bibliography is arranged in alphabetical order by author. An index provides a list of references by subject matter; tables summarizing site index curves and soil-site studies also are included. We would appreciate being notified of any errors, and also we would be glad to know of any publications that were omitted and should be included in a future supplement.

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Table 1. *Site index curves for conifer forest species*

Tree species	:	Area	:	Citation
Southern pines	:	Southern U.S.	:	USDA, FS (634)
Shortleaf & loblolly pine	:	Piedmont	:	Coile & Schumacher (146)
Shortleaf pine plantations	:	S. Illinois	:	Gilmore & Metcalf (266)
Loblolly pine plantations	:	S. Illinois	:	Gilmore & Metcalf (267)
Pitch pine	:	Pennsylvania	:	Illick & Aughanbaugh (329)
Virginia pine	:	Piedmont	:	Chaiken & Nelson (132)
do	:	N. Carolina	:	Slocum & Miller (552)
do	:	W. Virginia	:	Kulow et. al. (354)
Jack, red, and white pines	:	Lake States	:	Brown & Gevorkiantz (110)
Jack pine	:	Lake States	:	Sterrett (558)
do	:	Lake States	:	Eyre & LeBarron (189)
do	:	Lake States	:	Wackerman et. al. (650)
do	:	Lake States	:	Gevorkiantz (240)
Red pine	:	Lake States	:	Gevorkiantz (247)
do	:	N. Minnesota	:	Eyre & Zehngraff (190)
Red pine plantations	:	Illinois	:	Gilmore (259)
do	:	Connecticut	:	Bull (113)
White pine	:	Lake States	:	Gevorkiantz (246)
do	:	N. England & Mid-Atlantic	:	Frothingham (222)
do	:	S. Appalachians	:	Doolittle & Vimmerstedt (179)
do	:	S. Appalachians	:	Beck (78, 79)
White pine plantations	:	S. Appalachians	:	Vimmerstedt (645)
do	:	Illinois	:	Gilmore (260)
Ponderosa pine windbreaks	:	Nebraska	:	Sander (508)
Austrian pine windbreaks	:	Nebraska	:	Sander (509)
Red-cedar	:	Tennessee Valley	:	Hampf (288)
White spruce	:	Lake States	:	Gevorkiantz (245)
Black spruce	:	Lake States	:	Gevorkiantz (244)
do	:	Minnesota	:	Fox & Kruse (213)
do	:	Minnesota	:	LeBarron (373)
Spruces & balsam fir	:	N. Michigan	:	Bowman (100)
do	:	Northeast	:	Meyer (437)
Balsam fir	:	Lake States	:	Gevorkiantz (242)
White-cedar	:	Lake States	:	Gevorkiantz (243)
Tamarack	:	Lake States	:	Gevorkiantz (249)
European and Japanese larch	:	New York	:	Aird & Stone (5)

Table 2. — *Site index curves for hardwood forest species*

Tree species	Area	Citation
Upland oaks	Eastern States	Schnur (538)
do	Piedmont & S. Appalachians	Olson (459)
do	Michigan	Brown & Gevorkiantz (110)
Red oak	Lake States	Gevorkiantz (248)
Black, white, scarlet and chestnut oaks	Central States	Carmean (129, 130)
Red and white oaks	Arkansas	Graney and Bower (274)
Hickory	Central States & Appalachians	Boison and Newlin (99)
Yellow-poplar	Central States & Appalachians	McCarthy (416)
do	Piedmont & S. Appalachians	Beck (77)
Sugar maple, yellow birch, white ash, paper birch	Vermont	Curtis & Post (158)
Sugar maple, white ash	Vermont	Harrington & Howard (198)
Sugar maple	Vermont	Hawes & Chandler (303)
do	New York	Farnsworth & Leaf (197)
Red maple	Connecticut & Massachusetts	Hampf (288)
Beech	Northeast	Hampf (288)
Black cherry	New York	Hampf (288)
Paper birch	N. Wisconsin	Cooley (149, 150)
Aspens	Lake States	Kittredge & Gevorkiantz (343)
do	Lake States	Brown & Gevorkiantz (110)
do	Lake States	Gevorkiantz (241)
Black walnut plantations	Central States	Kellogg (336)
Black locust plantations	Central States	Kellogg (337)
Sweetgum	Maryland	Trenk (623)
do	South	Winters & Osbourne (775)
do	Mississippi Valley	Broadfoot & Krinard (109)
Cottonwood	Mississippi Valley	Broadfoot (107)
do	Central States	Neebe & Boyce (454)
Cherrybark oak	Mississippi Valley	Broadfoot (108)
Silver maple	Iowa	Brendemuehl et. al. (104)
Elm	Iowa	Brendemuehl et. al. (103)
Siberian elm windbreaks	Nebraska & Kansas	Sander (510)

Table 3. — *Soil-site studies for conifers*

Tree species	Area	Citation
Shortleaf pine	Missouri Ozarks	Fletcher & McDermott (207)
do	Missouri Ozarks	Nash (453)
do	Missouri Ozarks	Hartung & Lloyd (302)
do	Arkansas	Graney & Ferguson (275)
Shortleaf pine plantations	Missouri	Dingle & Burns (176)
do	S. Illinois	Gilmore (257)
Loblolly pine plantations	S. Illinois	Gilmore (258)
Red & white pine plantations	SE. Ohio & S. Indiana	Gaiser & Merz (230)
Red, white, and jack pine plantations	Wisconsin	Wilde et. al. (733-737, 742, 759)
Red pine plantations	Lower Michigan	Van Eck & Whiteside (637, 638)
do	Lower Michigan	Hannah (291)
do	Minnesota	Scott & Duncan (543)
do	New York	Richards et. al. (494)
do	New York	DeMent & Stone (168)
do	Massachusetts	Mader & Owen (408)
Red pine	Minnesota	Alban (8)
Jack pine	Minnesota	Pawluk & Arneman (463)
do	Minnesota	Pluth & Arneman (473)
do	N. Ontario	Chrosciewicz (138)
Black spruce	Quebec & Ontario	Lowry (393)
do	Quebec & Ontario	Vallee & Lowry (636)
Ponderosa pine	Black Hills	Myers & Van Deusen (452)
do	Black Hills	Mogren (447)
Redcedar	Missouri Ozarks	Arend & Collins (32)
European & Japanese larch	New York	Aird & Stone (5)

Table 4. — *Soil-site studies for hardwoods*

Tree species	Area	Citation
White oak	SE. Ohio	Gaiser (225)
do	SE. Ohio	Merz (432)
Black oak	SE. Ohio	Carmean (119-121, 124)
White & Black oaks	S. Indiana	Hannah (289, 290)
Upland oaks	NE. Iowa	Einspahr & McComb (187)
do	Arkansas Ozarks	Arend & Julander (35)
do	Missouri Ozarks	Hartung & Lloyd (302)
do	Iowa	Countryman & Thomson (153)
do	S. Michigan	Gysel & Arend (33, 282)
do	West Virginia	Trimble & Weitzman (627)
do	N. Appalachians	Lloyd & Lemmon (384)
Cherrybark oak	Mississippi Valley	Broadfoot (108)
Yellow-poplar, sweetgum, cherrybark oak	W. Tennessee	Hebb (305)
Yellow-poplar	Central States	Auten (52)
Yellow-poplar plantations	W. Indiana	Tryon et. al. (628)
do	S. Illinois	Gilmore et. al. (265)
Sugar maple	New England & Lake States	Post (474)
Northern hardwoods	N. Michigan	Westveld (665)
do	Vermont	Post & Curtis (476)
do	Vermont	Farrington & Howard (198)
do	New York	Farnsworth & Leaf (197)
Yellow & paper birch	New England & Lake States	Post et. al. (475)
Paper birch	N. Wisconsin	Cooley (150)
Trembling aspen	Minnesota & Wisconsin	Kittredge (340)
do	Minnesota & Wisconsin	Stoeckeler (571, 576)
do	N. Minnesota	Voigt et. al. (647)
do	N. Minnesota	Meyer (436)
do	N. Minnesota	Strothmann (607)
do	Wisconsin	Wilde & Pronin (752, 753)
do	Wisconsin	Fralish & Loucks (214)
Bigtooth aspen	Lower Michigan	Graham & Harrison (271)
do	Lower Michigan	Zahner & Crawford (783)
Black walnut plantations	SE. Iowa	Thomson & McComb (616, 618)
do	S. Illinois	Carmean (123)
do	S. Illinois	Losche (388)
Black walnut & black locust plantations	Central States	Auten (51)
Black walnut & green ash plantations	SE. Iowa	Hansen & McComb (296, 299)
Siberian elm windbreaks	Nebraska	Sander (512)
Sweetgum	Mississippi Valley	Broadfoot & Krinard (109)
Cottonwood	Mississippi Valley	Broadfoot (107)
Hybrid poplar plantations	Ohio	Kriebel et. al. (349)
Western catalpa plantations	Oklahoma	Walker & Reed (652)

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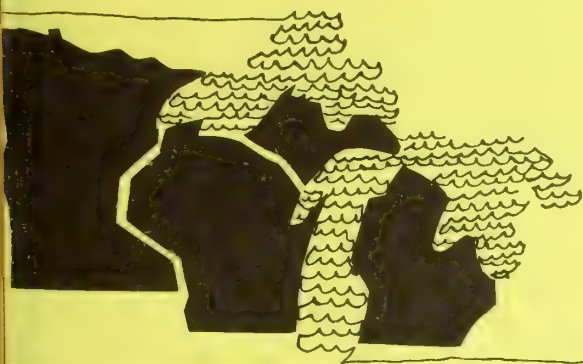
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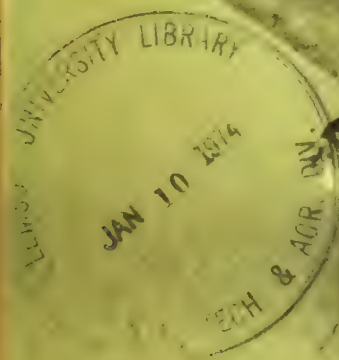


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**"A SUMMARY OF WHITE PINE  
BLISTER RUST RESEARCH  
IN THE LAKE STATES"**

**RALPH L. ANDERSON**



NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

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# A SUMMARY OF WHITE PINE BLISTER RUST RESEARCH IN THE LAKE STATES

Ralph L. Anderson

For several decades the term "white pine blister rust control" was essentially synonymous with the term "ribes eradication." During that period ribes eradication was a large-scale effort and little attention was given to alternative control methods. No serious questions were raised about the biological effectiveness of ribes eradication for controlling the rust, but some serious doubts were expressed concerning the economic justification for its application in some situations.

Since World War II methods for control of blister rust have undergone many dramatic changes. Major efforts have been directed to several alternative techniques. These include: identification of low-hazard sites, use of systemic fungicides, pathological pruning, and selection and breeding for genetic resistance. Sufficient evidence has also accumulated to question the effectiveness of the ribes eradication control method.

Over the past two decades the North Central Forest Experiment Station has directed major research attention to microclimatic relations and systemic fungicides and has been involved to a lesser extent in the other studies. Research by this Station on white pine blister rust, *Cronartium ribicola* J. C. Fischer ex Rabenh., recently was concluded. No new studies are planned for the immediate future. It is deemed appropriate, therefore, to summarize past white pine blister rust research and the present status of knowledge. That is the purpose of this paper.

## MICROCLIMATIC RELATIONS

Infection of white pine by blister rust is favored by extended periods of moderate temperature (below 67° F.) and the presence of free moisture on the needle surfaces (usually dew) during late summer and early fall when teliospores form on ribes leaves. Conversely, when either of these conditions is absent or frequently interrupted by higher temperatures and drying of the needle surfaces, the probability of infection is greatly reduced.

For these reasons, small differences in local climate can greatly influence prevalence of infection. The relations between climatic factors and prevalence of blister rust infection were studied by the staff at this Station from

1955 to 1968.<sup>1</sup> The Station received substantial cooperation from the University of Wisconsin and from the Division of Forest Pest Management, State & Private Forestry, USDA Forest Service. Results of these studies have been published by E. P. Van Arsdel and others (Anon. 1957, 1958; Van Arsdel 1954, 1961, 1962, 1964, 1965a, 1965b, 1967, 1968; Van Arsdel and Riker 1962). This research provided new knowledge and concepts that bear directly on effective control practices for blister rust. It also indicated promising approaches for study of other diseases sensitive to climatic conditions, such as *Scleroderma* canker.

Survey data collected by Forest Pest Management personnel and analyzed by King (1958) provided empirical evidence of variation in the hazard of blister rust infection for different areas of the Lake States region. The research on microclimate revealed the specific climatic influences that cause this variation and gave a sophisticated basis for dividing the region into broad blister rust hazard zones.

Hazard zones range from very low in the southern portion of the region to very high in some northern areas, such as the north shore of Lake Superior. In the low-hazard zone the potential for infection is so low that control is not justified. Thus, control programs were abandoned on large acreages that fell in the low-hazard category in the Lake States, Central States, and the Northeast.

As knowledge increased, hazard-zone maps were prepared. The latest version for the Lake States was published by Van Arsdel (1964) (fig. 1). Using similar concepts, Charlton (1963) developed a hazard-zone map for the northeastern States.

The primary objective of the microclimate studies was to determine relations between localized differences in microclimate and prevalence of blister rust infection. To achieve this objective and provide a practical tool for land managers to reduce losses, it was necessary

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<sup>1</sup>These studies were based on an earlier study made by E. P. Van Arsdel in 1951 to 1953 when he was a Research Assistant at the University of Wisconsin.

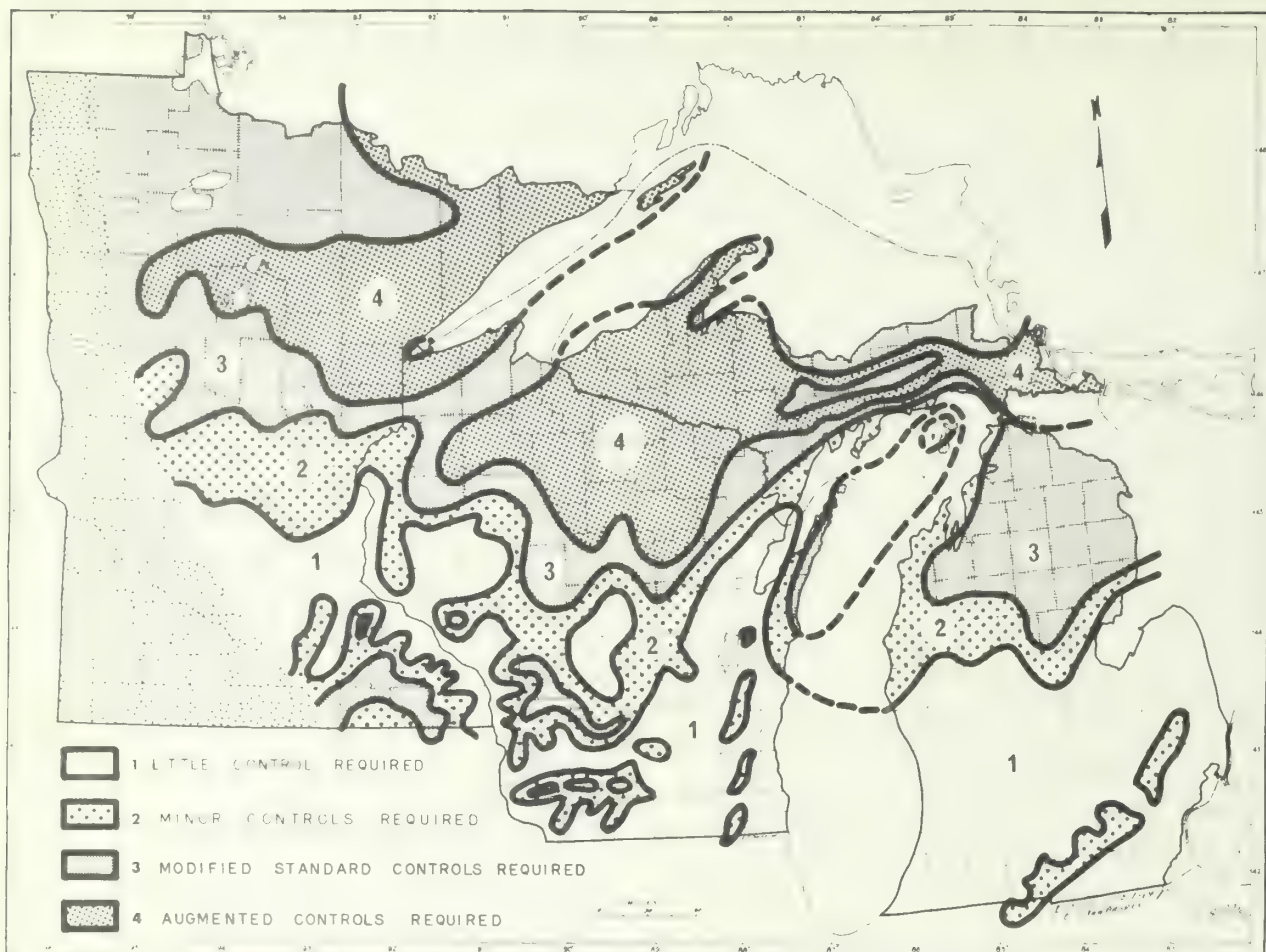


Figure 1.--Map showing climatic hazard zones for white pine blister rust infection potential, ranging from Zone 1 with low potential to Zone 4 with a very high potential.

to identify the features of the local environment that influence microclimate and determine how they modify the climatic factors that influence blister rust infection. In much of the Lake States, climatic conditions are marginal for infection and small differences in temperature or in the duration of favorable temperature and moisture conditions greatly influence prevalence of infection. Localized "spots" where infection levels differ from normal for a hazard zone result from microclimate effects, which, in turn, are created by features of the environment that can be recognized and interpreted.

Topography and vegetational cover are important features accounting for local variation in microclimate and hence variation in blister rust prevalence. The effect of topography is most pronounced during the clear, cool, windless nights that also favor dew formation. The coolest air flows downslope and accumulates in depressions forming a microclimatic zone cooler

than that found upslope. Also, north-facing slopes are cooler because they are exposed to less intense solar radiation of shorter duration. Therefore, more favorable infection conditions are found in these situations.

Thus, one can assess local topography and predict its effect on the risk of infection. For example, a topographic effect favoring infection at the base of a north slope can be predicted. In such a location there is both accumulation of down-flowing cool air and low exposure to solar radiation. The opposite effect would occur on the upper part of a south-facing slope because of no accumulation of cool air and maximum exposure to solar radiation.

The influence of vegetation on microclimate is more complex than that of topography. Vegetation, for all practical purposes, has the same effect as topographic relief on downslope flow of cool air. Cool air flows down over the tops of a sloping tree canopy in the same manner as

it does a hillside. Dense vegetation functions as air dams in essentially the same way as a ridge or cliff, and cool air will flow into and accumulate in an opening in a tree canopy the same as it would in a topographic depression. Another example of this kind of effect would be a dense belt of vegetation running across an otherwise open slope. This belt of vegetation will function as an air dam, and cool air will accumulate on its upslope side in the same manner as it does at the base of a slope.

To interpret other important effects of vegetation, some understanding is required of heat radiation principles, both incoming solar radiation and outgoing heat radiation, or loss of heat, to a clear sky. Incoming solar radiation is partly reflected and partly absorbed by the surface that intercepts the sun's rays. The energy of the absorbed radiation is later emitted as radiant energy. This phenomenon causes a substantial difference in the sunny, daytime environment of an open area exposed to the sun compared to that of a shaded area under a tree crown canopy. In an opening, incoming radiation is intercepted by the ground or low vegetation and maximum temperature buildup is close to the ground. Where a tree canopy is present, radiation is intercepted by the upper crowns and maximum temperature buildup is at that level. Temperature under the crowns is much lower and understory vegetation is not exposed to as high daytime temperature.

However, night temperatures will be lower in openings because of inflowing cool air and, when there is no cloud cover, because of direct exposure of the foliage on small trees to a clear sky; hence, an outward radiation of heat energy. Where there is a crown canopy, cooling by radiation to a clear sky is limited to the upper crown surfaces. Radiation from understory trees is reflected down by the underside of the overstory canopy and a higher night temperature environment is maintained in the understory.

The lowest temperature regime for a 24-hour period occurs in small openings. As used here, a small opening is one in which direct sunlight does not reach the bottom of the opening; i.e., it is shaded by the surrounding tree canopy. In this situation there is no direct input of heat energy but continuous outward radiation of heat; therefore, temperatures are lower both by day and by night.

Vegetation also plays a major microclimatic role in the infection process by influencing dew formation. Dew provides the free moisture that must be present a minimum of several hours for successful germination and penetration of pine needles by blister rust spores. Dew forms on plant surfaces that are cooled when they radiate heat to a clear sky. Thus, in openings, dew forms on the low-lying vegetation including

small white pine. If an overstory tree canopy is present, dew forms on the overstory canopy with little or none on understory vegetation. Moreover, dew persists longest in small openings where it is not "burned off" by solar radiation.

In summary, the probability of favorable temperature and moisture conditions persisting long enough for infection to occur is greatest in small openings and least in an understory--primarily because of lack of adequate free moisture on the needles. The probability of favorable conditions for infection in large openings is about average because, although nighttime conditions are very favorable, this favorable period is shortened by the rapid rise in temperature and drying shortly after sunrise.

Detailed information on the influences of topography and vegetational cover on risk of blister rust infection are presented in several publications (Van Arsdel 1961, 1962, 1964, 1965a; Van Arsdel *et al.* 1961).

During the later stages of research on microclimate, much of the effort was shifted to study of local influences on air currents. Air currents transport the rust spores from ribes bushes to white pine (fig. 2). In late summer and early fall, when basidiospores (sporidia)

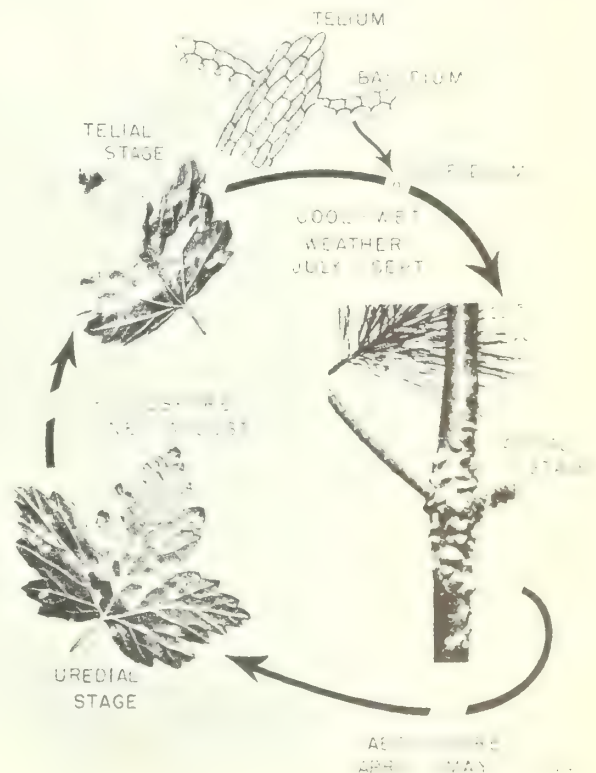


Figure 2.--Life cycle of the rust showing typical signs and the spore stages occurring on white pine and ribes.

are available to infect pine, the most favorable temperature and moisture conditions for infection occur during cool, clear, "still-air" periods characterized by heavy dew formation. If there is a wind, dew does not form; hence, even though temperature may be satisfactory, essential moisture is missing. Rainy periods do not appear to be as favorable for infection as might be presumed, because rain tends to wash spores out of the air and off of pine needles. Therefore, low-velocity, local air movements associated with cool, clear conditions are important to effective transport of spores from ribes to pine.

Close correlation was found between prevailing air-movement patterns during periods favorable for infection and the location of areas with high and low levels of blister rust infection. Apparently, local features of topography and vegetation influence the pattern of air currents that transport viable rust basidiospores.

An example of a small-scale effect is a young white pine plantation on a slope above a swamp containing a dense population of ribes (fig. 3). On the lower portion of such a slope,

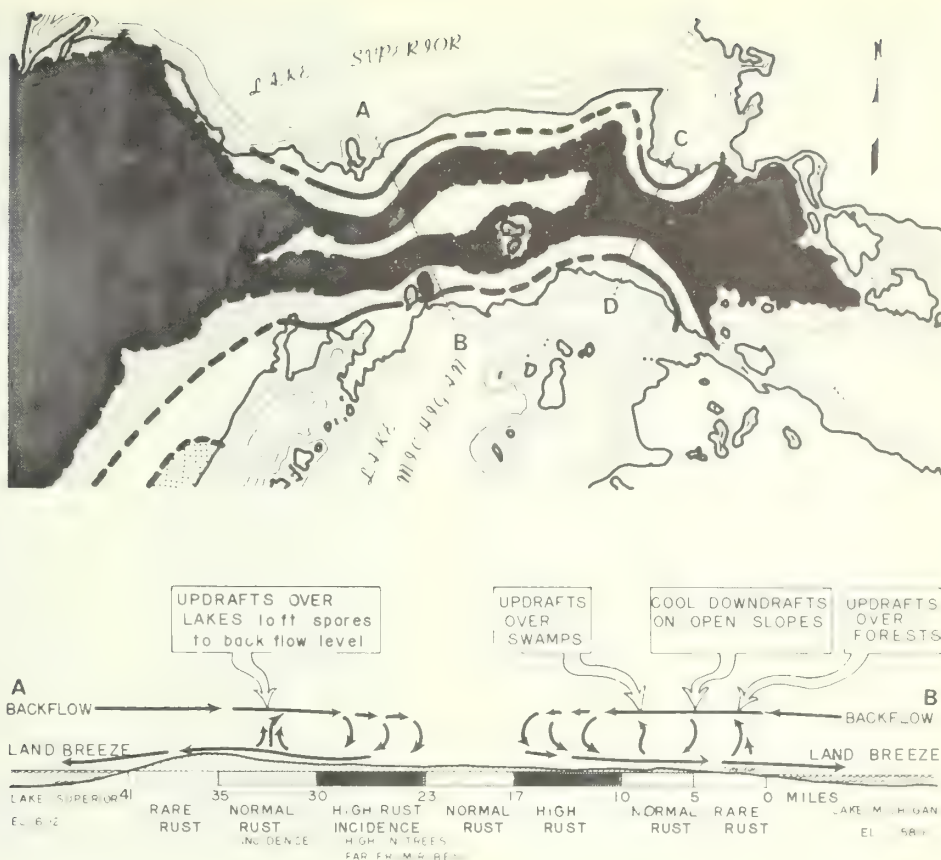
next to the swamp, white pine is lightly infected by rust while pine at the top of the slope, farthest from the swamp, is heavily infected. Studies made when conditions were favorable for infection showed that there is a surface flow of cool air downslope from the plantation out into the swamp. This air diffuses into the tree canopy, forcing air from under the canopy vertically until it meets a temperature inversion layer. The air then flows back toward the upper end of the plantation as a counter current under the inversion layer intersecting the ground surface where rust infection is heaviest (Van Arsdel 1965a, 1965b, 1967).

An example of a large-scale effect is air movement over land and water on nights favorable for infection (fig. 4). The more rapid cooling at night of the air mass over land than over water causes a flow of cool air from land to water. This forces the warmer air over the water upward and then back over the land mass as a counter-current. In a study adjacent to Lake Michigan this countercurrent came down to the land surface several miles inland. There a much higher concentration of blister rust infection was found than in white pine located elsewhere in



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Figure 3.--Smoke movements show air currents that match the spread of white pine blister rust from swamp ribes to upland white pines in northeastern Wisconsin.



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Figure 4.--Map (top) shows areas of types of blister rust distribution. Diagram (bottom) shows night land breezes and backflows that give this spread pattern. Shadings for rust spread zones are the same in the chart and map.

the area. Similar evidence was obtained from observations in other areas with a comparable land-water relation. Evidently, viable basidiospores of blister rust are carried by such air currents for at least a few miles. This possibility is highly significant because control of blister rust by ribes eradication has been based on the assumption that viable basidiospores of the rust can be transported for only a few hundred yards even under the most favorable conditions. Long-distance transport of basidiospores is believed to be a major factor contributing to the failure of ribes eradication to prevent blister rust infection on some very high-hazard sites in the northern part of the region (Van Arsdel 1965a, 1965b, 1967).

Evidence also suggests another air current relation. In the southern parts of the region, in typical low-hazard areas, most infections on pine are within a few feet of the ground. This, in part, is because the microclimate close to the ground is more favorable for successful infection. It is, however, probably also a reflection of successful basidiospore transport being

limited to local, close-to-the-ground, air currents. Apparently the fragile basidiospores die when transported at higher levels because of less favorable temperature and moisture conditions.

Generally, as one goes northward the prevalence of blister rust increases and the distribution of rust infection changes. More cankers are found higher on the trees until in some high-hazard zones many blister rust flags are seen in the upper crowns of saw-log trees.

Apparently, the vertical distribution of infections reflects the favorableness of the local climate for infection and indicates the distance viable basidiospores are transported by air currents. This is based on the premise that in high-hazard zones air currents high above the ground favor basidiospore survival and that such air currents move spores for longer distances.

In conclusion, studies show that microclimatic effects caused by features such as topography, water bodies, and vegetation influence

revalence and distribution of blister rust infections. Knowledge of these relations can help minimize losses from the disease by fitting management and control practices to local conditions.

## CHEMICAL CONTROL WITH ANTIBIOTICS

During the 1950's antibiotics were tested for control of blister rust in the western white pine region. The results appeared successful, and the blister rust control program was shifted from ribes eradication to application of antibiotics (Moss 1961, Moss *et al.* 1960). This shift was not based solely on the interpretation of the test results but reflected the desperate need for a treatment that would eradicate the many existing infections in white pine (Benedict 1966).

Antibiotics were applied by either of two methods: to individual trees by the basal stem method, in which the antibiotic was mixed in a fuel oil carrier and sprayed onto the lower 6 feet of the bole and the base of branches entering the bole in this zone; or by aerial spraying, usually by helicopter, in which the antibiotic was mixed either in water or in a water-fuel oil emulsion and applied to the foliage.

Either of two antibiotics, Acti-dione (cycloheximide) and phytoactin,<sup>2</sup> was used in basal stem application. Cycloheximide was found to be phytotoxic when applied to pine foliage. Most aerial applications were made with phytoactin, but less phytotoxic derivatives of cycloheximide were also used on a limited scale.

By 1960 several small-scale tests of phytoactin and Acti-dione on eastern white pine (*Pinus strobus* L.) had been established. Results were far from conclusive. Therefore, in 1962 the Station and Region 9, USDA Forest Service, cooperatively initiated large-scale testing of antibiotics for control of white pine blister rust on eastern white pine. The principal objective was to test the efficacy of cycloheximide and phytoactin, using formulations and methods of application developed in the West. By 1965 it was apparent that none of the antibiotic formulations and methods of application were effective. The evaluations were continued for 2 more years to determine if there were any delayed reactions to the treatments, but all results remained negative (Phelps and Weber 1966, 1970b). Powers and Stegall (1965) came to the same conclusion in the Southeast in their evaluation of cycloheximide for control of blister rust on eastern white pine.

<sup>2</sup>Use of trade names does not constitute endorsement of the products by the USDA Forest Service.

Concurrent with studies on eastern white pine, a comprehensive evaluation was made in the West on western white pine (*Pinus monticola* Dougl.) (Benedict 1966, Dimond 1966, Ketcham *et al.* 1968). Conclusions were that adequate control was not being obtained, and the large-scale antibiotic control program was abandoned.

Phelps and Weber (1969a, 1970a) also tested a number of solvents and dilutants (other than the standard #2 fuel oil) and a large number of chemicals (other than phytoactin and cycloheximide). None of these were any better than the materials used in the West.

Other methods of applying antibiotics also were tried, such as whole tree drenches (Phelps and Weber 1966, 1970b), various applications to seedlings (Phelps and Weber 1968), and direct treatment of scarified cankers as had been done in some of the early testing in the West (Moss *et al.* 1960). Only one treatment showed promise of being effective in eradicating blister rust cankers: if cankers were thoroughly scarified, including the apparently healthy bark around the canker, and then treated directly with cycloheximide in fuel oil, they usually died (Phelps and Weber 1966, 1970b).

This method is not considered practical operationally. The action obtained is not a systemic action but rather chemical excision; i.e., the chemical is sufficiently phytotoxic so that the large quantity absorbed by scarified bark kills the host tissue occupied by the rust, and the rust, being an obligate parasite, is also killed. Even fuel oil alone has some suppressing effect on the rust when applied with scarification. To kill the canker the chemical must be applied directly to each potentially lethal blister rust infection on a tree, because the chemical is not effectively translocated from the site of application to a site of infection. Furthermore, scarification of the canker and surrounding area must be thorough. This is time consuming and difficult to achieve. Also, inasmuch as scarification must extend a few inches beyond the margins of the cankers, the bark must be killed over a large portion of the tree's circumference at the point of infection. The same type of control can be achieved by mechanical excision of the canker and immediately surrounding bark tissues (Martin and Gravatt 1954, Stewart 1957).

Much was gained from the studies on antibiotics although an effective systemic treatment was not found. The natural characteristics of blister rust cankers were found to vary greatly. Large deviations from the "classic textbook" (fig. 5) description have been described by Phelps and Weber (1969b). Misinterpretation of such natural variations contributed to early conclusions that the antibiotics were effective.

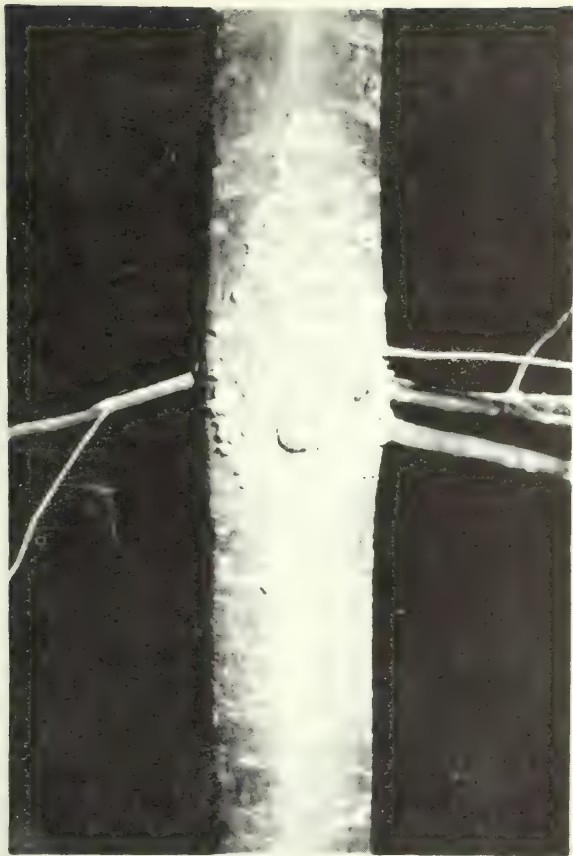


Figure 5.--A typical white pine blister rust canker photographed in late spring when aecia are present. More often than not this portion of a canker will have been chewed by rodents and a heavy pitch flow will occur.

Characteristics considered evidence of antibiotic action were found to be normal when many untreated check cankers were included in subsequent experiments.

No effective systemic fungicide treatment is known for white pine blister rust. Such a system would be unique in that it would eradicate infection on all parts of a tree. Regardless of the control methods used as a standard practice, a good systemic fungicide would be valuable for special uses such as cleaning up an area before establishing a preventive control practice or to clean up a new wave of infection in an area normally not hit hard.

Although cycloheximide and phytoactin are ineffective, it should not be construed that other systemic fungicides would not be. Antibiotics are used effectively for some plant diseases. Although no systemic action against blister rust was obtained with cycloheximide and phytoactin, bioassay analysis showed that these antibiotics are absorbed and translocated throughout white pine trees (Phelps and Leapheart 1968,

Phelps and Weber 1967). The shortcoming was that these specific chemicals--at least in the quantities absorbed and translocated--were not active against the pathogen when they reached the site of infection. Further efforts to find the right chemical and the optimum conditions for absorption and translocation are needed.

#### PRUNING AS A CONTROL METHOD

Pruning shows some promise as a blister rust control technique (Martin and Gravatt 1954, Stewart 1957). It has been used to some extent in recent control programs. Blister rust infection occurs by invasion of the pine needles and then advances into the bark tissues. So, except on small seedlings, most infections initiate on branches. Pruning can therefore control infection in two ways: (1) cutting off an infected branch before the rust has advanced from the branch into the main stem eliminates the infection with no damage to the tree; (2) cutting off the lower branches eliminates the needle-bearing surface of the tree that is closest to the ground and the most vulnerable to infection.

During the early 1960's some small-scale studies of pruning as a blister rust control method in a high-hazard area demonstrated that pruning substantially reduces blister rust losses (Weber 1964). Several factors, however, limit the practical use of this technique.

Young eastern white pine is most susceptible to infection and mortality. If the objective is to protect most of the white pine natural regeneration or plantation stock established on an area, pruning must begin much earlier than for other silvicultural objectives. Also, trees must be pruned often enough to keep the lower third of the bole free of branches.

Severe white pine weevil infestation also can complicate the situation: investment in rust control is not practical unless the weevil is also controlled.

The distribution of blister rust infections on trees poses another problem. In rust-hazard zones where most infections occur near the ground, pruning is a good means of eliminating potentially lethal infections. But where infection occurs in the upper crowns of larger trees, pruning is impractical. Unless the rotation is short, many pruned trees would probably be killed later by infections originating too high on the tree to be pruned out.

#### SELECTION AND BREEDING FOR RESISTANCE

The North Central Forest Experiment Station has done little research on genetic resistance to white pine blister rust. However, progress

is being made on this problem by others. Much of this work is pertinent to Lake States white pine and, in view of the importance of this approach to control of blister rust, merits summarizing.

Since World War II much effort has been devoted to development of genetic resistance to white pine blister rust by selection and breeding. Major efforts are being made on all three commercial white pines; i.e., eastern white pine (*Pinus strobus* L.), western white pine, and sugar pine (*Pinus lambertiana* Dougl.).

Genetic resistance to blister rust is present in all three species, and some of the resistant individuals do transmit a degree of resistance to their progeny (Bingham *et al.* 1969, Kinloch *et al.* 1970, Patton and Riker 1966). This prompted initiation of a large-scale program by Region 9, USDA Forest Service, to develop rust-resistant seed orchards for eastern white pine. Several hundred potential parent trees have been selected and are being tested for ability to transmit resistance. Trees known to be resistant are also being propagated by grafting to create first-generation seed orchards.

Genetic resistance is regarded as the most desirable form of disease prevention because progeny from resistant parents can be outplanted with no further need for rust control. Cost is limited to that needed to develop adequate parent material and resistant progeny beyond the cost of other means of regeneration.

The most serious potential problem in using genetic resistance is pathogenic races of the pathogen. Most genetic resistance that has been developed in economic plants is of the "vertical" or "differential" type (Van der Plank 1968, 1969) and is specific for certain races of a pathogen. When a new crop variety was developed, genetic resistance was built in for those races prevailing in the regions where the variety was to be used. When such a variety is put into production, other races of the pathogen develop. Eventually a new crop variety incorporating resistance to these "new races" must be created to replace the one previously used. A new variety of annual agricultural plants can be developed and put into large-scale production within a few years; it takes much longer for trees. The problem of races could best be overcome by developing "horizontal" or "uniform" resistance (Van der Plank 1968, 1969), i.e., non-race specific resistance, but plant breeders have had less success in creating this type of resistance.

Bingham *et al.* (1971) demonstrated that there are pathogenic races of white pine blister rust. What effect will this have on rust resistant white pine? Instead of an annual crop

exposed to a season's infection, a white pine crop is exposed for several decades during which rust races could develop through many changes. If a new race appeared that infected previously resistant selections of pine, a long period would be required to develop new selections resistant to the new race.

The potential of the blister rust race problem is very real. It is not certain, however, that resistant white pine will fall victim to devastating rust race changes. Plant pathologists and plant geneticists in agriculture are working toward developing disease-resistant varieties that should not be so vulnerable to new races of pathogens. Until horizontal resistance can be developed an alternative is to develop several lines of white pine differing from each other in the genetic basis of resistance and plant them in mixtures. Thus, only a portion of the trees in any given stand should be vulnerable to any "new race" that might develop. This is the short-term approach to blister rust resistance; in the long run, it is hoped that more reliance can be placed on developing horizontal resistance.

A factor that might influence the race problem on white pine is the stage in the rust's life cycle that infects white pine. Agricultural crops affected by serious rust race problems are infected by stages of the rust's life cycle in which each pathogen cell has a 2N chromosome number and is capable of propagating itself vegetatively on that host indefinitely without going through the sexual stage and the attendant recombination of genes. This means that once a given genotype has appeared, it can persist with that specific genetic constitution for as long as susceptible hosts are available.

White pine, on the other hand, is infected by the 1N chromosome number stage in the blister rust's life cycle. This stage is not capable of vegetative propagation and is produced by the telial stage on the ribes host. In the telial stage, the rust undergoes combination and segregation of genes. This means that massive populations of a single 1N genotype by vegetative propagation, such as occurs in 2N stages of the many rusts on agricultural crops, cannot develop. Although this indicates that the genetic constitution and propagation of a pathogenic race of blister rust on white pine is different, the end result for practical purposes could be about the same.

Because the white pine blister rust fungus does contain genetic diversity for pathogenicity on white pine, some trees resistant to only some of the possible "races" of rust probably would eventually become infected. If such trees were extensively planted, this could create a "breeding ground" for less prevalent genotypes to which they were susceptible. Even though lack

of vegetative propagation of a pathogenic genotype would preclude rapid buildup, there would be active selection for the alleles of those genes controlling pathogenicity that permitted infection of the available host material. This means there would be a gradual buildup of those alleles permitting infection of the "resistant white pines" that had been widely planted. However, this trend could be diminished because the rust has to also live on another host, ribes. Usually, a race that has great virulence on one host is less aggressive on alternate hosts and so does not increase as rapidly.

Probably this process would be much slower than that typical for buildup of a 2N race. But when one considers the much greater length of a white pine rotation as compared to agricultural crops and the time required to create new resistant selections to replace those attacked, it could appear that the race buildup situation could be more serious for pine than for an annual crop.

This suggests that in blister rust resistance development programs, economically acceptable low levels of infection on "resistant" trees should not be ignored. At least some such infections could indicate presence of rare alleles for pathogenicity in the rust population. These could build up on "resistant" tree populations if there were no block to their spread and intensification, such as low aggressiveness on ribes hosts.

In limited research on this problem, evidence was found of pathogenic races for the 2N stage on ribes (Anderson and French 1955) (fig. 6). This proved genetic variability but most certainly did not prove that the rust varies in pathogenicity in the 1N stage on pine. As mentioned earlier, this question has now been resolved by others (Bingham *et al.* 1971).

The evidence for races on ribes could have more practical significance than we assumed at the time this work was done. The evidence indicates that the rust's virulence or aggressiveness does vary on the ribes host, which in turn can influence the populations of various rust races available to infect pine. Although progress on development of genetic resistance has been made, it will be many years before plantations of resistant trees contribute much to the eastern white pine resource. Most of our eastern white pines and their natural progeny will be subject to blister rust damage for a long time unless other controls are effectively applied in the interim. This emphasizes the desirability of not putting all research and development effort on genetic resistance.



Figure 6.--Two ribes leaves from a single clone inoculated at the same time with different sources of white pine blister rust urediospores and then incubated in the same way. The genetic difference between the two rust collections is demonstrated by the difference in the characteristics of individual pustules on the two leaves, not by the difference in number of infections.

#### CONTROL BY RIBES ERADICATION

Control of white pine blister rust by eradication of ribes was first applied in 1909. It gradually expanded to become the largest tree disease control program ever undertaken. Until the early 1950's it was the blister rust control method, and ribes eradication became essentially synonymous with blister rust control. Since the early 1950's it has been largely replaced by other methods.

Until about 1960 ribes eradication was assumed to be an effective control. Questions often were raised about the economic justification for applying the method in many specific situations, but no one seriously questioned its biological effectiveness. It was assumed that if the local population of ribes were removed, white pine would not become infected.

Within the past few years, however, the effectiveness of ribes eradication has been challenged. Several individuals began to doubt its universal effectiveness both on the basis of research results (such as evidence for long-distance dissemination) and because of high infection rates in some areas essentially devoid of ribes either naturally or by eradication. These doubts culminated in a large-scale evaluation survey on the effectiveness of ribes eradication in the western white pine type. It was concluded that ribes eradication did not reduce the infection rate to acceptable levels. As a consequence, the ribes eradication program was abandoned in the western white pine type (Ketcham *et al.* 1968). Results of the study

were consistent for all areas sampled, suggesting that the general climate for the western white pine region is sufficiently favorable for blister rust infection to give rise to unacceptable rates of infection.

Our research on microclimatic relations suggests a different situation in the eastern white pine region. Here we have a range of broad-hazard zones plus local effects caused by microclimate variations. In the low-hazard zone, the general prevalence of rust infection is so low that control is not needed. The real question on effectiveness of ribes eradication applies only to the high- and intermediate-hazard zones. On some sites in the high-hazard zone there is strong circumstantial evidence for long-distance dissemination of viable blister rust sporidia, suggesting that ribes eradication would not be effective.

The most likely area in which ribes eradication might provide practical control is the intermediate-hazard zones, on sites where evidence suggests that dissemination is more local. Local microclimate effects also influence the situation. Until more evidence is available, it is difficult to speculate as to the total area involved where infection levels are high enough to justify control.

The evidence for lack of effectiveness of ribes eradication raises an interesting question: how could such a massive control operation be applied for several decades before serious questions were raised concerning its biological soundness? Two important factors may have created this situation. First, initial tests of ribes eradication likely were made in areas where effective spore dissemination was local. If so, the error was in making a broad generalization based on a few nonrepresentative examples. Errors in generalizing from a few specific examples certainly are not unique, but this may be a classic example with far-reaching consequences. These studies and decisions were made before foresters and related professionals had acquired adequate comprehension of statistical methods or an appreciation for the complex variations in the ecology of habitats.

Second, the postcontrol evaluation system involved re-examination from time to time of areas from which ribes had been eradicated. If infections that had originated since eradication of the ribes were found, it was assumed that regrowth of ribes or missed ribes provided the necessary alternate host material. In most cases, ribes were found and the area was scheduled for a rework. Although control personnel were perplexed by some situations where new infection was occurring without any evident local ribes, no systematic assessment of this phenomenon was made in the eastern white pine region.

The width of the protective zone from which ribes were eradicated around white pine stands was modified from time to time. Apparently these modifications were made without benefit of carefully designed tests. In some cases the protective zone was modified to provide as much protection as possible with limited available funds. In others, transfer of "practical experience" in one hazard zone to another may have been involved.

We now know from microclimate studies that the width as well as shape of protective zones could be important and vary with locality, depending upon the direction of the airflow patterns and distance of effective dissemination.

## CONCLUSIONS

What can or should be done about the white pine blister rust problem in the Lake States? A final conclusion is not possible because of uncertainty about the effectiveness of ribes eradication in some situations. However, the following conclusions concerning control of the disease appear relevant:

1. On most sites in the low-rust-hazard zone, white pine blister rust does not cause serious losses and can be largely ignored. Fear of blister rust has had a much more serious impact on the growing of white pine than have losses from the disease. White pine should be considered a desirable species in this zone, although the white pine weevil can cause considerable damage. In general, white pine grows well in this area and alternative species on many sites are low- or intermediate-quality hardwoods. An additional argument for favoring white pine in this zone is that elm and oak, two of the more common alternative species, are suffering severe losses from Dutch elm disease and oak wilt. Oak wilt is most serious in Wisconsin and Minnesota.

2. In the intermediate-rust-hazard zones, blister rust losses can be appreciably reduced. Sites characterized by a microclimate favorable for rust infection should be avoided and an overstory should be maintained over juvenile white pine. In areas where most rust infections are close to the ground and economics permit, pruning will greatly reduce rust losses and upgrade tree quality.

3. In the high-hazard zone there doubtless also are some areas where methods recommended for intermediate-hazard zones would be reasonably effective. However, there are many areas--especially those where long-distance dissemination occurs--where it appears that losses would not be reduced to an acceptable level by any of the methods available at this time. Generally, white pine should not be planted on these areas.

The great diversity of rust infection hazard between and within climatic zones, because of microclimatic variations, indicates the danger of making broad, rule-of-thumb generalizations for a specific control technique over large regions. Each local situation must be evaluated, the amount and distribution of infection observed, and local experience with a control method evaluated. Then, tailor-make any control program to the local situation.

Much research effort has been directed to the white pine blister rust problem and much progress has been made. Nevertheless, it is evident that more research effort is needed for satisfactory resolution of the problem. The following are regarded as the most important problems needing attention:

1. In areas where rust losses are serious genetic resistance must be developed that will endure, at least long enough to permit trees to grow to merchantable size. Development of the best possible genetic resistance to blister rust will require continuing research.

2. An effective antibiotic control for white pine blister rust would be desirable. Even if economic and other factors precluded its general and widespread use, it would have great utility for use on high-value stands and trees. Examples are some recreational areas and where an unusually severe wave of infection caused by an abnormally favorable infection weather hits an otherwise low-hazard area. It also could be used to preserve desirable genetic material until such time as it could be incorporated in trees with stable resistance to blister rust.

3. The role of ribes eradication in controlling blister rust in eastern white pine must be resolved.

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## PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.



# WILDERNESS ECOLOGY:



THE UPLAND PLANT  
COMMUNITIES, WOODY BROWSE  
PRODUCTION, AND SMALL  
MAMMALS OF TWO ADJACENT  
33-YEAR-OLD WILDFIRE  
AREAS IN NORTHEASTERN  
MINNESOTA



The trend toward integrated multidisciplinary research is increasing. The research arm of the Forest Service recognizes the desirability of this approach. While not strictly a multidisciplinary effort, this instance of three studies conducted simultaneously on the same sample areas is a start toward integration of research effort. Small mammal populations, amount of woody browse available for large herbivores, and the composition and structure of the plant communities are all highly interrelated. Reporting all three related study results in one publication seems both logical and efficient.

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WILDERNESS ECOLOGY: THE UPLAND PLANT COMMUNITIES, WOODY BROWSE PRODUCTION,  
AND SMALL MAMMALS OF TWO ADJACENT 33-YEAR-OLD WILDFIRE AREAS OF  
NORTHEASTERN MINNESOTA

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## PART I. THE UPLAND PLANT COMMUNITIES

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### ABSTRACT

The present upland vegetation of two adjacent wildfire areas that burned 33 years ago consists of four plant community types: aspen, aspen-birch, jack pine-birch, and jack pine. These types were identified through cluster and canonical analysis of species frequency of occurrence data from 33 sample stands located randomly over the two areas. Present vegetation differences appear to relate better to the type and condition of vegetation present before the fire than to measured environmental parameter differences found between the types.

The virgin forest communities of the Boundary Waters Canoe Area in northeastern Minnesota probably owe a major portion of their variation in composition and structure to the presence of wildfire over the past 400 years (Heinselman 1969, 1970). Ohmann and Ream (1971b) studying mature upland virgin plant communities of the BWCA concluded that (1) the length of time elapsed since last major disturbance (usually fire) and (2) the type of vegetation present at the time of that disturbance were important factors in determining the structure and composition of the present plant communities. Early postfire vegetation response has been described by Ahlgren (1960) and is currently being studied in detail on seven plant communities following a recent (1971) 15,000-acre wildfire in the BWCA.<sup>1/</sup>

Since periodic fires are apparently fundamental to the vegetation of the area, it is important to document the structure and composition of the postfire plant communities intermediate in age between those described by Ohmann and Ream (1971b) and Ahlgren (1960). Thus, the present paper quantitatively describes and classifies intermediate-aged upland virgin vegetation. Because it is intended to complement quantitative ecological baseline data that were previously published for the mature virgin plant communities of the BWCA (Ohmann and Ream 1971b), it includes extensive tabular data for each plant community defined in this study.

### OBJECTIVES

One objective of the study was to classify and describe the upland plant communities resulting from wildfire 33 years ago. A second objective was to examine further the hypothesis that time elapsed since disturbance, and the

vegetation present at the time of disturbance, are more important than differences in environmental parameters in determining the structure and composition of present plant communities over a small region such as the BWCA (Ohmann and Ream 1971b). If elapsed time since last major disturbance is unimportant, we should expect many of the same plant communities described for the mature forest to be also present on the study area where time since disturbance is a constant. Preburn aerial photographs allow at least superficial examination of preburn vegetation. The relationship of certain environmental factors (other than fire) to the resultant communities could also be examined.

### STUDY AREA

BWCA fires were compiled for the period 1936-1966 by Brown<sup>2/</sup> from National Forest Administration Fire Reports. Analysis of his compilation showed that of 155 wildfires occurring during that period, only 41 burned areas were unlogged or partly unlogged and only 14 of these were 5 acres or larger in size. Six of the 14 fires occurred in upland vegetation and of these, two were 5 acres, one 18 acres, one 158 acres, and two were over 3,000 acres. The two large wildfires were assumed to be more typical (in terms of size and thus variability of effect) of past fires in the area and were chosen for study.

No two wildfires are likely to produce the exact same effects; however, the fires that burned the Frost Lake and Cherokee Lake areas seem to have had comparable impact and produced similar effects, making them suitable for a combined study. Similarities include:

<sup>1/</sup> Office report on file at North Central Forest Experiment Station, St. Paul, Minn.

<sup>2/</sup> Data on file, North Central Forest Experiment Station, St. Paul, Minn.

	FROST LAKE FIRE	CHEROKEE LAKE FIRE
Location of fire origin	T-64N, R-4W, S-36	T-64N, R-4W, S-27
Date of fire start	7-11-36	8-12-36
Duration of fire	10 days	9 days
Major timber types burned:		
NH (Hardwoods)	2,295 acres	1,899 acres
A (Aspen)	363	92
J (Jack pine)	--	611
Sp (Black spruce)	--	568
Yp-J (Red pine-Jack pine)	153	--
Sp-T (Black spruce-Tamarack)	326	--
Wp (White pine)	136	10
Balsam fir	119	12
Br (Brush)	--	7
Total acres burned	3,392	3,199

The timber type symbols above are from the 1936 fire reports. Although the type symbols in the fire reports are different, J and Yp-J probably refer broadly to the same type, and similarly for Sp and Sp-T. Types in parentheses are our interpretations of the major species that the symbols represent.

Thus, two areas were chosen for study that burned under similar fire conditions during the same fire season, that cover the same acreage in essentially the same timber types, and that lie adjacent to each other (fig. 1).

## METHODS

### Prefield

The major vegetation types on the two burn areas were identified from 1961 aerial photographs and outlined on U.S. Geological Survey topograph maps. From these maps the acreage of each type was estimated by dot-grid overlay.

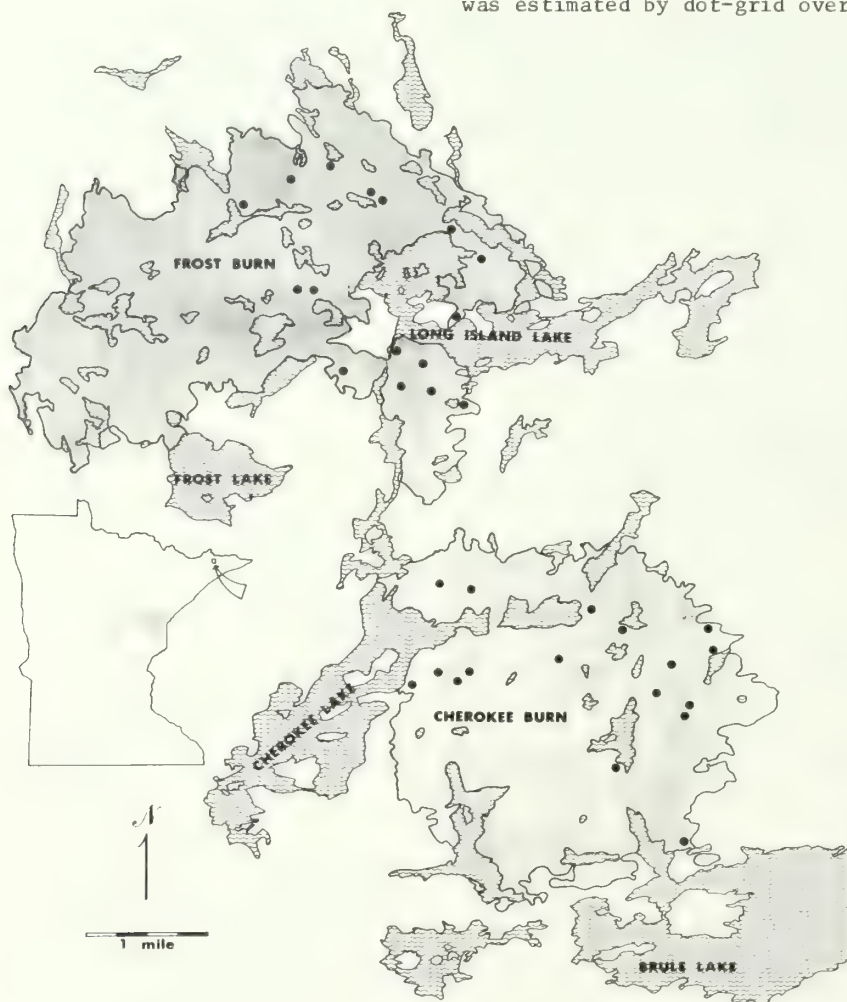


Figure 1.--Frost Lake and Cherokee Lake study area with sample locations indicated by dots.

Potential sample sites were located within the two areas by using a random-numbers table and grid overlay on the quadrangle maps. Randomization was restricted with the criterion that the sample contain both north- and south-facing aspects for each of the major upland vegetation types in each burn area. Seventy-two locations were selected and plotted under the assumption that at least one-half of these would meet the field criteria for acceptance and could be sampled during the 1969 field season. Thirty-three stands were selected for sampling.

### Field

Methods have been described in detail by Ohmann and Ream (1971a). Briefly, they consist of the following: only upland plant communities, defined as those in which surface water never accumulates, were sampled. The minimum size of each sampled area was normally about 5 acres, and only sites uniform in topography and vegetation were acceptable. Twenty points were examined within each stand to sample the vegetation. The point-centered quarter method (Cottam and Curtis 1956) was used for trees. Because of the immaturity of these forests, and thus smaller diameter of the trees, the tree size class included all stems more than 1 inch in diameter at breast height (d.b.h.). Circular milacre plots were used for tree seedlings (all stems less than 1 inch d.b.h.) and tall shrubs, and rectangular 1 x 2 foot plots were used for other vegetative components. General environmental information including elevation, slope, aspect, and distance to water were measured and recorded for each stand. A soil pit was dug and samples of the mineral horizon were collected. Surface organic horizons were never deeper than 6 inches and ground-water tables were not near the surface.

### Numerical Analysis

The general analytical procedures outlined for other BWCA plant community studies (Ohmann and Ream 1971a, Ream and Ohmann 1971) were used in this study. Specific classification philosophy and procedures are detailed in Ohmann and Ream (1971b). Use of canonical ordination (Goldstein and Grigal 1972) in place of the principal component ordination used in the earlier study (Ohmann and Ream 1971b), however, necessitated a reduction in the number of species used in the classification and ordination portion of this analysis.

It is generally accepted that only a few representatives of the flora of a region will occur and/or be sampled within any one small randomly selected stand. Therefore, the sample data as a matrix of species values within stands is expected to contain many zero values. Analysis of such a matrix creates problems both because of the large core-storage requirement for the computer and because some multivariate techniques (like canonical ordination) may fail when many zeros occur in the input matrix. For these reasons, we decided to reduce the number of species used in the classification process.

An effort was made to reduce species number with some objectivity. Thus, species were selected on the basis of occurrence in at least half of the sampled stands. A few species "groups" were removed from consideration in this process (e.g., grasses, sedges, lichens, other than *Cladonia* species, and mosses other than the feather mosses). Within the occurrence criterion, we selected 30 species which represented all strata of the forest: trees, tree seedlings, tall shrubs, low shrubs, herbs, and moss-lichens. The number of species selected in each stratum reflected that stratum's contribution to the total flora of the study.

Percent frequency of occurrence within each sample stand for the selected species was subjected to a polythetic agglomerative numerical classification based on within-group dispersion using standard distance (Grigal and Goldstein 1971, Goldstein and Grigal 1972). The classification produces a hierarchy of stand relationships (fig. 2).

Thirteen stand groups from different levels of the classification hierarchy were subjected to canonical ordination (Goldstein and Grigal 1972) (fig. 3). The stands which were common to the stand groups comprising the regional nodes that resulted from the ordination were re-ordinated as new stand groups (fig. 4).

### Environmental Parameter Analysis

Samples of mineral soil (B horizon) were analyzed for exchangeable calcium, magnesium, potassium, and sodium by shaking 5 grams of soil in 20 ml neutral normal ammonium acetate for one-half hour. This mixture was filtered and leached with an additional 80 ml of ammonium acetate. Calcium and magnesium were analyzed on a Perkin Elmer atomic absorption spectrophotometer Model 303.<sup>3/</sup> Sodium and potassium were analyzed on a Perkin Elmer flame photometer. Exchangeable hydrogen was measured by the  $\text{BaCl}_2$ -Triethanolamine, pH 8.1 method. Extractable phosphorus was analyzed by shaking 5 grams of soil for 5 minutes in 50 ml of Bray's No. 1 solution (0.025 N HCl - 0.03 N  $\text{NH}_3\text{F}$ ). Molybdophosphoric blue color was developed and read on a Klett Summerson Colorimeter. Acidity (pH) was determined on a 1:1 soil-water mixture by a Beckman Zeromatic pH meter.

Mineral soil samples were analyzed by a modification of the hydrometer method (Bouyoucos 1951) for percent sand, silt, and clay. Moisture retention capacity was determined by pressure membrane extraction at 15 and pressure plate extraction at 1/3 atmospheres (Richards 1954).

Environmental data were summarized for each of the plant community types generated by the numerical analysis. The mean value and standard error

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<sup>3/</sup> Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

of each parameter for each type were calculated and plotted. The presence of differences between

means was detected by use of the Student-Newman-Keuls multiple-range test (Steel and Torrie 1960).

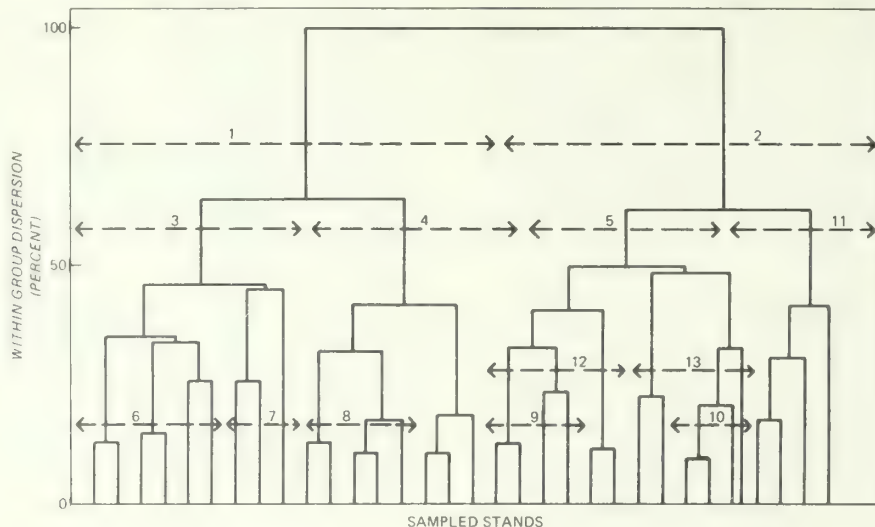


Figure 2.--Dendrogram representing the numerical classification of 33 sampled stands from the Frost Lake and Cherokee Lake wildfire areas. Dashed lines enclose stand groups subjected to canonical ordination.

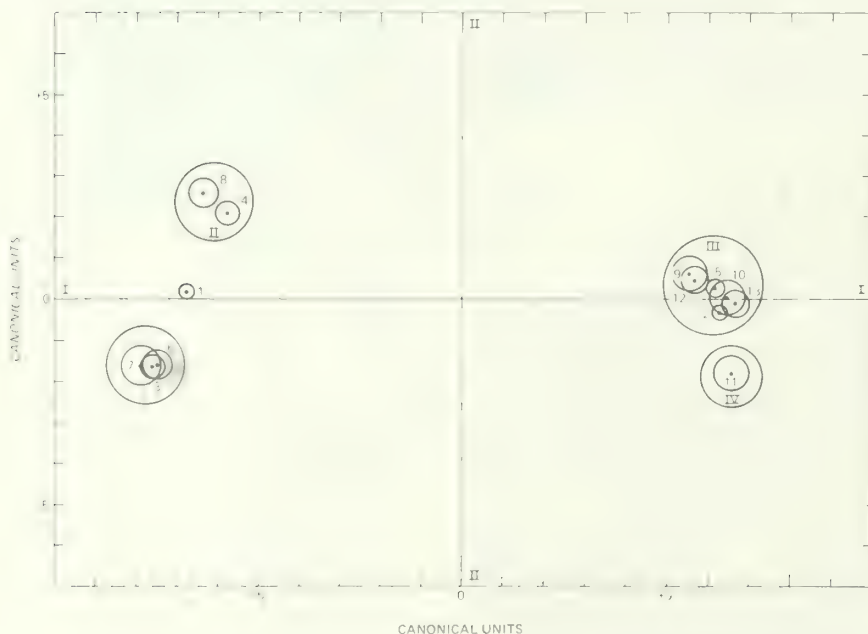


Figure 3.--Position along first two canonical axes of stand groups 1 through 13 from the dendrogram (figure 2). Small circles represent 90 percent confidence intervals around group means. These two axes account for 95 percent of the variation. Large circles surrounding more than one stand group represent regional nodes I, II, III, and IV whose stands held in common were reordinated as new stand groups.

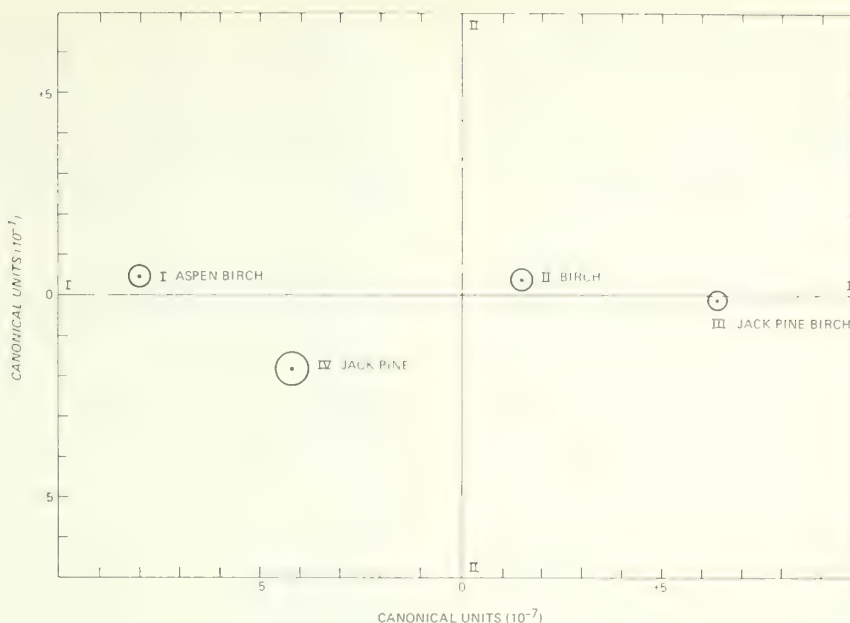


Figure 4.--Position along first two canonical axes of stand groups comprising regional nodes I, II, III, and IV from the Frost Lake and Cherokee Lake wildfire areas. Circles represent 90 percent confidence intervals around group means. Note that axis I scale units are multiplied by  $(10^{-7})$  and axis II units by  $(10^{-1})$ . These axes account for nearly 100 percent of the variation.

### Preburn Vegetation Analysis

Partial stereo-coverage for the area is available from 1934 aerial photographs. Unfortunately, the photo scale is smaller than that of the 1961 photos and the quality is highly variable, but the preburn cover type and degree of canopy cover were determined where possible.

### RESULTS AND DISCUSSION

#### The Sample

Prior to the sampling procedure four upland vegetation types, aspen-birch, jack pine, upland brush, and rock outcrop, were identified and delimited on 1961 aerial photographs (table 1) through photo interpretation. Based simply on this interpretation process, aspen-birch is clearly the major vegetation type of the Frost Lake area, while aspen-birch and jack pine are of similar areal extent on the Cherokee Lake area. When the selected sites were visited, we found that what we had classified as upland brush and rock outcrop in 1961 consisted of forest or open-grown trees in 1969. We disregarded this change and proceeded to sample as in the original schedule. The original sample assignment included 72 potential sites distributed throughout the four upland types on both north and south slopes, and 33 of these stands were sampled. Sixteen stands were sampled in the Frost Lake area; four from areas originally typed aspen-birch, five jack pine, three upland brush,

and four rock outcrop. Seventeen stands were sampled in the Cherokee Lake area; three original typed aspen-birch, five jack pine, four upland brush, and five rock outcrop.

Table 1.--Vegetation type acreage estimates based on 1961 aerial photographs of the Frost and Cherokee wildfire areas prior to sampling (Acres)

Vegetation type	Frost Lake	Cherokee Lake
Aspen-birch	2,069	1,312
Jack pine	373	1,471
Upland brush	509	160
Rock outcrop	169	64
Lowland brush	204	160
Swamp conifer	68	32
Total	3,392	3,199

#### Classification and Ordination

The goal of classification is to combine those stands which are most similar floristically. Any two samples of vegetation can be found to differ if sufficient detail is considered, but samples can also be combined at various levels of similarity and useful generalizations made about

the composition and structure of the groups. Thirty species were selected for use in the classification and ordination procedure (table 2).

Table 2.--Species selected for use in the classification and ordination procedures defining the plant communities of the Frost and Cherokee Lakes wildfire areas

Stratum	Species
Tree	<i>Pinus banksiana</i> <i>Larix laricina</i>
Tall shrub	<i>Prunus pensylvanica</i> <i>Amelanchier</i> spp. <i>Salix bebbiana</i>
Tree seedling	<i>Abies balsamea</i> <i>Picea mariana</i> <i>Larix laricina</i>
Low shrub	<i>Rubus pubescens</i>
Herbaceous	<i>Galium triflorum</i> <i>Linnaea borealis</i> <i>Maianthemum canadense</i> <i>Streptopus roseus</i> <i>Epilobium angustifolium</i> <i>Trientalis borealis</i>
Moss-lichen	<i>Calliergonella schreberi</i> <i>Dicranum</i> spp. <i>Cladonia rangiferina</i> <i>Polytrichum</i> spp.

The percent of selected species in each stratum category--trees, tall shrubs, tree seedlings, low shrubs, herbaceous, and moss-lichen--approaches (by design) the percent of all species represented in these same categories for the entire sample. The classification used was polythetic agglomerative based on within-group dispersion using standard distance (Orloci 1967). The results of the classification can be depicted diagrammatically as a dendrogram (fig. 2) which shows the combining of stands at various levels of within-group dispersion until all are combined at the 100-percent level.

We wished to know which stand combinations best represented identifiable community types. The stands comprising each stand group (1 through 13) of figure 2 were ordinated. Those stand groups which are most similar or contain many of the same stands (e.g., groups 9 and 12) would be expected to fall near each other in the ordination.

The stand groups are located along axes I and II of the ordination (fig. 3). All of the stand groups from the left half of the dendrogram fell along the left half of axis I and all from the right half aligned along the right half of axis I. Stand group 1 is comprised of all the stands that also make up dendrogram groups 3, 4, 6, 7, and 8, and on the ordination it falls about midway between those stand groups. Stand groups 4 and 8, which have five stands in common, fall near each other. Stand group 3 and its subgroups (6 and 7) all fall near each other with their confidence intervals overlapping.

Except for group 11 all the stand groups from the right side of the dendrogram (fig. 2) fall near each other in the ordination, and their

confidence intervals overlap. We believe this means group 11 is dissimilar from the other, more closely related groups of this portion of the dendrogram.

Circles were drawn around those stand groups that appear to be closely related on the first two axes of the canonical analysis (fig. 3). Only two axes were considered because the first axis represented 92 percent of the variation and the second axis accounted for 3 percent more, while the remaining eight axes combined accounted for only 5 percent. The encircled areas were designated as regional nodes I, II, III, and IV, and stands common to each area were re-ordinated as new stand groups (fig. 4). We interpret the broad separation in these two axes of multidimensional space as a useful level of generalization to distinguish between the groups of stands. Throughout the remainder of this report we describe the upland vegetation of the two burn area in terms of four plant community types composed of the stand groups I-IV on the final ordination, or in terms of the dendrogram (fig. 2), groups 3, 4, 5, and 11, respectively, at the 55 percent within-group dispersion level.

### The Plant Communities

The four community types generated through the classification-ordination process we termed aspen-birch, birch, jack pine-birch, and jack pine based on the most important contributors to the tree stratum. About equal numbers of the 33 sampled stands are classified as aspen-birch and birch, 9 and 8, respectively (table 3). Only four stands make up the jack pine type, and the remaining 12 stands form the jack pine-birch community type. Three of the types are unequally distributed between the two burns. All of the birch stands are on the Frost Lake burn, while the Cherokee Lake burn contains all but one of the aspen-birch stands and all of the jack pine stands.

Table 3.--A comparison of the four plant community types delimited for the Frost Lake and Cherokee Lake wildfire areas

Item	Community type			
	Aspen-birch	Birch	Jack pine-birch	Jack pine
Number of sampled stands	9	8	12	4
Frost Lake area	1	8	7	0
Cherokee Lake area	8	0	5	4
Number of stands presampling typed				
Aspen-birch	3	4	0	0
Jack pine	0	0	7	3
Upland brush	3	1	2	1
Rock outcrop	3	3	3	0
Tree stratum				
Basal area (ft <sup>2</sup> /acre)	100	88	149	160
Density (stems/acre)	1,585	3,056	3,198	1,575
Tall shrub stratum				
Basal area (ft <sup>2</sup> /acre)	10	3	2	2
Density (stems/acre)	9,567	5,269	2,129	3,163
Tree seedling stratum				
Cover (percent)	8	11	1	2
Density (stems/acre)	7,622	7,981	12,713	2,975
Low shrub stratum				
Cover (percent)	6	3	3	2
Herbaceous stratum				
Cover (percent)	53	46	21	50
Moss-lichen stratum				
Cover (percent)	9	7	16	15

The types resulting from the classification corresponded reasonably well with those from the aerial photo typing. Sample areas typed from the photos as aspen-birch are members of the aspen-birch or birch types and those typed as jack pine are jack pine-birch or jack pine. All but one of the stands typed as upland brush and rock outcrop are members of the aspen-birch, birch, or jack pine-birch types.

Tree basal area is greatest in the communities having a significant amount of jack pine (*Pinus banksiana*)<sup>4/</sup> in the canopy, while tree density is highest where paper birch (*Betula papyrifera*) is significant. The birch, where common, are obviously more numerous but smaller in diameter. However, analysis of age data from sample trees in each stand indicates no significant difference in average age of the birch [30.2 years (n = 30)] compared to jack pine [31.9 years (n = 67)] or quaking aspen (*Populus tremuloides*) [30.8 years (n = 49)].

While tree basal area and density values of mature upland plant communities in the BWCA reported by Ohmann and Ream (1971b) would not be expected to be equivalent to the immature communities of this study, it is useful to compare the range of values. The basal area value of the 1936 aspen-birch community (100 square feet per acre) is about the same as that for the mature aspen-birch community type elsewhere (90 square feet). Density values are very dissimilar, however, with only 483 stems per acre in the mature community, about one-third the value for the 1936 burn area aspen-birch type. The closest equivalent to the 1936 jack pine community is the jack pine (oak) community type of the mature forest (Ohmann and Ream 1971b). Again the basal area values are somewhat similar (160 versus 110 square feet per acre, respectively), but the density values are quite different (1,575 versus 602 stems per acre, respectively). There is no close equivalent of the birch community in the mature forest, but we can compare this type to the fir-birch community under the assumption that the presence of balsam fir (*Abies balsamea*) trees and seedlings in the 1936 birch stands are indicative of a succession to fir-birch. The comparative values are 97 square feet and 707 stems per acre for the fir-birch type versus 88 square feet and 5,269 stems per acre for the 1936 birch type. A loss of a third or more of the present stems can therefore be expected during maturation of the communities in these burns.

The tall shrubs are best represented in the aspen-birch type, both in terms of basal area

4/ Scientific names for tree species follow Little (1953); those for shrubs and herbs follow Gleason (1963) with a few exceptions, in which either Lakela (1965) or Fernald (1950) are used. Scientific names for lichens follow Hale and Culbertson (1965), and those for mosses follow Grout (1928-1940).

and density, and both values decrease with an increase in the amount of conifers in the canopy (table 3). This follows the general pattern found in the mature communities where the deciduous plant communities contain by far the greatest number of tall shrub stems per acre.

Part of the difference among the four types in total tree seedlings can be accounted for by the occurrence of balsam fir (table 3). The jack pine-birch type has the greatest number and percent cover of tree seedlings, and also the most balsam fir, whereas the jack pine type has the lowest total seedling numbers and cover and also the fewest balsam fir. However, even when the balsam fir are deducted, there is still a considerable difference among types (aspen-birch 5,755; birch 3,931; jack pine-birch, 7,571; and jack pine 2,950 stems per acre).

There appears to be less difference among the communities in percent cover in the other vegetative classes (table 3). Total cover values for the herbaceous and low shrub categories are somewhat higher in the aspen-birch than in the other types, while total cover for lichens and mosses is higher where jack pine is an important canopy member.

The low occurrence of blueberry and wintergreen in all four of the communities seems inconsistent with their general occurrence in the mature plant communities and in comparison to their presence following a 1971 wildfire in the BWCA (unpublished data). Twenty of the stands were, therefore, revisited and in each, 20 one-by-two-foot plots were established and checked for the presence of *Gaultheria procumbens*, *Vaccinium angustifolium*, and *V. myrtillus*. A particular effort was made to check the stands of the jack pine and jack pine-birch communities where these species would be expected. These species were less frequent than they are in communities of the mature forest (table 4). We believe this is an indication of the severity of the two 1936 fires which burned in mid-summer of drought year. The 1971 fire referred to above

Table 4.--A comparison of presence in stands and average frequency of occurrence in sample plots of three species in the plant communities of the Frost Lake and Cherokee Lake wildfire areas and in the mature virgin plant communities of the BWCA

(In percent)

CHEROKEE LAKE-FROST LAKE COMMUNITIES						
Community	<i>Gaultheria procumbens</i>		<i>Vaccinium angustifolium</i>		<i>Vaccinium myrtillus</i>	
	Presence	Frequency	Presence	Frequency	Presence	Frequency
Aspen-birch	0	0	0	0	0	0
Birch	0	0	0	0	20	1
Jack pine-birch	11	1	22	4	31	4
Jack pine	0	0	0	0	25	5
MATURE VIRGIN COMMUNITIES						
Jack pine (oak)	100	45	90	54	27	3
Aspen-birch	0	0	46	8	62	10
Fir-birch	0	0	12	1	50	5

was a spring fire in which little of the duff was removed by burning. These species sprouted vigorously the same growing season following the fire. Heavy-fruited species such as wintergreen and blueberry may require a long time to become reestablished in an area following a severe fire that has consumed everything down to the mineral soil.

#### Aspen-Birch Community

Paper birch and quaking aspen together dominate the tree stratum of this community, each having an average of 40 square feet of basal area per acre (table 5). The birch are of smaller diameter, however, having an average density of 895 stems compared with 512 aspen stems per acre. Birch is also more common; e.g., it is more likely to be found at any point within a stand as is indicated by the commonness index (presence x frequency). Jack pine, occurring in eight of the nine stands in the type, also has a considerable basal area, but is scattered with an average of only 43 stems per acre. Three tree species--white spruce (*Picea glauca*), mountain-ash (*Sorbus americana*), and black spruce (*Picea mariana*)--are more numerous than jack pine, but they are of much lower basal area. White spruce, while not abundant, occurred in eight of the nine stands comprising the type--more frequently than in any other type. Balsam fir and white-cedar (*Thuja occidentalis*) are also present. White-cedar occurred in the tree size class only in this community type.

The most abundant and most common tall shrub species is mountain maple (*Acer spicatum*) with an average of 5,200 stems and 2.1 square feet of basal area, more than in any other type. Beaked hazel (*Corylus cornuta*) is a significant member of the tall shrub stratum, but did not occur in all stands. While considerably less numerous and common than mountain maple, beaked hazel outnumbers mountain maple in two stands within the type. Bebb willow (*Salix bebbiana*) with an average of only 370 stems makes up half the total shrub basal area, but the basal area is high because of several stems in one quadrat which had attained the stature and diameter of the canopy trees. Pincherry (*Prunus pensylvanica*) occurred in eight of the nine stands and frequently in the sample plots, but is low in density, probably because of its single-stem habit of growth. It is a representative of the immediate postfire stages of regeneration, and thus the individual stems are of large average size and contribute significantly to the basal area (0.6 square foot) despite its low density. Other tall shrubs present are fly honeysuckle (*Lonicera canadensis*), juneberry (*Amelanchier* spp.), round-leaved dogwood (*Cornus rugosa*), speckled alder (*Alnus rugosa*), green alder (*A. crispa*), and common elder (*Sambucus canadensis*). The latter species was encountered only in this community type.

Paper birch is the most important tree seedling of the community with an average of

3,944 stems per acre and a ground cover of 1.6 percent (table 5). It is consistently present in high numbers in all but one stand within the type. Balsam fir seedlings occur nearly as frequently as birch as is indicated by their similar indices of commonness, and fir also has a similarly high cover value (2.0 percent) but is much lower in average density (1,867 stems per acre). In only three stands within the type does fir outnumber birch.

White-cedar and black spruce seedlings are also important in terms of cover. While the cedar is about the same average density as balsam fir, it occurred in only five of the nine stands in the type and as a seedling is important only in this community. Black spruce is much lower in average density and occurred in six of the nine stands. Other seedling species present include white spruce (in low numbers but present in all but one stand), quaking aspen, mountain-ash, red maple (*Acer rubrum*), jack pine, and white pine (*Pinus strobus*). The seedling composition indicates a trend toward a community type like that of the fir-birch community of the mature forest (Ohmann and Ream 1971b).

The most important low shrubs of the community are dewberry (*Rubus pubescens*) and bush honeysuckle (*Diervilla lonicera*), with dewberry by far the most common (table 5). It has a consistently higher cover than in any other type. Red raspberry (*Rubus strigosus*) and wild rose (*Rosa acicularis*) are probably remnants of early postfire stages and are still of some importance, although not occurring in every example of the type.

Species composition of the herbaceous stratum is, in general, the same as that of the mature aspen-birch community, except that fewer species were encountered, probably because of this more restricted sampling region. In fact, the five most important species here were among the six most important of the mature community and have about the same ground cover values. Six species not present in the mature community were recorded in this type, but of these, one occurred in single plots in two stands, and the rest occurred in a single plot. Large-leaf northern aster (*Aster macrophyllus*) has the highest average percent ground cover of the herbs, although it is not consistently high. Other important species are bunchberry (*Cornus canadensis*), wild sarsaparilla (*Aralia nudicaulis*), false lily-of-the-valley (*Maianthemum canadense*), violets (*Viola* spp.), Clinton's lily (*Clintonia borealis*), sweet bedstraw (*Galium triflorum*), and grasses.

The moss-lichen stratum is slightly better developed here than in the mature aspen-birch community (Ohmann and Ream 1971b) and is similarly dominated by mosses, although many lichen species are present (table 5).

Table 5.--Summary of Frost Lake and Cherokee Lake wildfire areas aspen-birch plant community

Species and ground cover:	Presence : in stands	Average frequency : in sample plots : within stands	Average : density	Average : basal : area	Average : cover	Average : relative : frequency	Average : relative : density	Average : relative : dominance	Average : importance : value	Commonness : index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<b>TREES</b>										
Betula papyrifera	100	82	895	40	--	43	50	39	44	8,167
Populus tremuloides	100	69	512	40	--	35	37	39	37	6,889
Picea glauca	89	12	54	3	--	6	3	3	4	1,086
Pinus banksiana	89	12	43	13	--	6	4	14	8	1,086
Picea mariana	44	13	44	3	--	6	4	3	4	593
Abies balsamea	56	6	24	1	--	3	2	1	2	309
Sorbus americana	44	6	72	X	--	3	2	2	4	272
Thuja occidentalis	33	3	13	X	--	2	1	X	1	111
<b>TALL SHRUBS</b>										
Acer spicatum	100	48	5,172	2	--	33	40	25	33	4,778
Corylus cornuta	78	25	2,583	2	--	16	25	20	20	1,944
Prunus pensylvanica	89	18	261	1	--	14	5	13	11	1,580
Salix spp.	44	11	494	1	--	7	5	7	6	469
Salix bebbiana	44	9	372	5	--	8	8	20	12	395
Amelanchier spp.	67	3	89	X	--	3	1	X	1	222
Lonicera canadensis	44	4	233	X	--	3	4	1	3	198
Alnus crispa	44	4	328	1	--	3	4	10	6	173
Cornus rugosa	22	1	17	X	--	1	X	X	1	25
Sambucus canadensis	11	1	6	X	--	X	X	X	X	6
Alnus rugosa	11	1	11	X	--	X	X	X	X	6
<b>TREE SEEDLINGS</b>										
Betula papyrifera	100	37	3,944	--	2	31	54	27	37	3,722
Abies balsamea	100	36	1,867	--	2	26	22	20	22	3,611
Populus tremuloides	89	14	339	--	X	12	5	5	7	1,235
Picea glauca	89	8	83	--	X	6	1	6	4	691
Picea mariana	67	9	156	--	1	8	2	25	12	630
Thuja occidentalis	56	11	1,078	--	2	7	13	14	12	586
Sorbus americana	44	6	72	--	X	4	1	1	2	272
Pinus banksiana	33	3	33	--	X	3	1	1	1	111
Acer rubrum	33	2	44	--	X	2	1	1	1	74
Pinus strobus	11	1	6	--	X	X	X	1	X	6
<b>LOW SHRUBS</b>										
Rubus pubescens	100	31	--	--	2	53	--	40	46	3,111
Diervilla lonicera	89	9	--	--	3	19	--	36	28	840
Rubus strigosus	67	8	--	--	X	13	--	5	9	556
Rosa acicularis	67	4	--	--	1	7	--	7	7	296
Vaccinium myrtilloides	33	2	--	--	X	4	--	6	5	56
Ribes spp.	11	1	--	--	X	2	--	5	4	12
Ribes triste	11	1	--	--	X	1	--	X	X	12
Ribes glandulosum	11	1	--	--	X	X	--	X	X	6
Vaccinium angustifolium	11	1	--	--	X	1	--	X	X	6
Chimaphila umbellata	11	1	--	--	X	1	--	X	1	6
<b>HERBACEOUS</b>										
Aster macrophyllus	100	71	--	--	23	17	--	43	30	7,111
Cornus canadensis	100	66	--	--	7	16	--	15	15	6,611
Aralia nudicaulis	100	57	--	--	7	13	--	13	13	5,667
Gramineae	100	33	--	--	2	8	--	4	6	3,278
Maianthemum canadense	100	28	--	--	2	7	--	4	5	2,778
Viola spp.	100	27	--	--	1	6	--	2	4	2,722
Galium triflorum	89	16	--	--	X	4	--	1	2	1,432
Clintonia borealis	89	14	--	--	2	3	--	3	3	1,235
Linnaea borealis	78	12	--	--	1	3	--	2	3	907
Epilobium angustifolium	89	10	--	--	1	2	--	1	2	889
Cyperaceae	78	10	--	--	1	2	--	1	2	778
Trientalis borealis	67	12	--	--	1	3	--	2	2	778
Streptopus roseus	78	9	--	--	1	2	--	2	2	691
Lycopodium clavatum	67	7	--	--	1	2	--	2	2	482
Lycopodium obscurum	56	6	--	--	X	1	--	1	1	340
Apocynum androsaemifolium	56	5	--	--	X	1	--	1	1	278
Anaphalis margaritacea	44	3	--	--	X	1	--	1	1	148
Pyrola rotundifolia	33	4	--	--	X	1	--	X	1	130
Melampyrum lineare	44	3	--	--	X	1	--	X	1	124
Waldsteinia fragarioides	33	2	--	--	X	1	--	X	X	74
Equisetum spp.	33	2	--	--	X	X	--	X	X	56
Dryopteris spinulosa	22	2	--	--	X	X	--	X	X	49
Fragaria vesca	22	2	--	--	X	X	--	X	X	37
Pteridium aquilinum	22	2	--	--	X	X	--	1	X	37
Pyrola elliptica	22	1	--	--	X	X	--	X	X	25
Lathyrus ochroleucus	22	1	--	--	X	X	--	X	X	25
Aster ciliolatus	22	1	--	--	X	X	--	X	X	25
Gymnocarpium dryopteris	11	2	--	--	X	X	--	1	X	19
Goodyera tessellata	11	2	--	--	X	X	--	X	X	19
Lycopodium annotinum	11	1	--	--	X	X	--	X	X	12
Goodyera repens	11	1	--	--	X	X	--	X	X	12
Petasites palmatus	11	1	--	--	X	X	--	X	X	6
Dryopteris Phegopteris	11	1	--	--	X	X	--	X	X	6
Pyrola secunda	11	1	--	--	X	X	--	X	X	6
Mitella nuda	11	1	--	--	X	X	--	X	X	6
Solidago hispida	11	1	--	--	X	X	--	X	X	6
Actea rubra	11	1	--	--	X	X	--	X	X	6
Anemone quinquefolia	11	1	--	--	X	X	--	X	X	6

Continued on next page

Table 5 continued

Species and ground cover	Presence in stands	Average frequency in sample plots within stands	Average density	Average basal area	Average cover	Average relative frequency	Average relative density	Average relative dominance	Average importance value	Commonness <sup>1/</sup> index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<u>MOSS-LICHEN</u>										
Dicranum spp.	100	43	--	--	2	11	--	2	7	4,278
Other mosses	89	42	--	--	2	10	--	2	6	3,074
Calliergonella schreberi	100	34	--	--	3	9	--	3	6	3,389
Polytrichum spp.	100	29	--	--	1	8	--	1	5	2,889
Other lichens	78	29	--	--	1	7	--	1	4	2,247
Cladonia rangiferina	67	8	--	--	X	2	--	X	1	556
Hypnum crista-castrensis	33	2	--	--	X	X	--	X	X	56
Cladonia sylvatica	22	2	--	--	X	X	--	X	X	37
Cladonia alpestris	11	2	--	--	X	X	--	X	X	19
Cladonia mitis	11	1	--	--	X	X	--	X	X	6
Hylocomium splendens	11	1	--	--	X	X	--	X	X	6
<u>GROUND CHARACTERISTICS</u>										
Litter	100	100	--	--	85	27	--	84	56	10,000
Dead wood	100	37	--	--	3	10	--	3	6	3,722
Live wood	89	38	--	--	1	11	--	1	6	3,358
Bare rock	78	12	--	--	2	3	--	2	2	907
Bare ground	33	2	--	--	X	X	--	X	X	56

X denotes values of less than one percent.

<sup>1/</sup> The commonness index is not always an exact product of presence and frequency here because these two factors were rounded for this table after the commonness index was determined.

## Birch Community

The tree stratum of this community is characterized by many small paper birch trees with scattered larger-diameter quaking aspen. Paper birch has an average density of 2,458 stems and basal area of 54 square feet per acre (table 6). Its high index of commonness (9,800) indicates that it is present at nearly every point in every stand. While aspen are fewer in number, they are present in all but one stand within the type and make up nearly a quarter of the total basal area. Jack pine and balsam fir are a distant third in basal area followed by white pine, white spruce, black spruce, and mountain-ash. Balsam fir is present in all but two stands of the type and has a higher average density than in the other types. White spruce is less important than in the aspen-birch type.

The major tall shrub is beaked hazel with an average density of 2,613 stems and 1.6 square feet of basal area (table 6). Each of these values represents at least half of the total for all tall shrubs. It is the only species present in all stands of the type. Mountain maple with an average density of 1,125 stems and 0.4 square foot of basal area is present in all but one stand. Fly honeysuckle, round-leaved dogwood, and chokecherry (*Prunus virginiana*) all attain their greatest abundance in this community, though together they have an average density of only 1,179 stems, 0.2 foot of basal area, and are not present in every stand within the type. Other species represented are pincherry, bebb willow, juneberry, hairy climbing honeysuckle (*Lonicera hirsuta*), and speckled alder.

Balsam fir and paper birch are the most important tree seedlings with an average density of 4,050 and 3,225 stems, and percent ground

cover of 5.6 and 3.0, respectively (table 6). In this type they are both consistently of high value with each being the more numerous in half the examples of the type. White spruce and black spruce seedlings are also important because of their relatively large size; each contributes about 1 percent cover while numbering only about 100 stems (table 6). White spruce is present in all but one stand of the type and is of about the same importance as in the aspen-birch type. Black spruce is present in only one-half the stands and is less important than in the aspen-birch type. White-cedar is considerably less important here than in the aspen-birch type. Other seedlings present are quaking aspen, mountain-ash, white-cedar, red maple, white pine, and jack pine. The two deciduous communities thus have similar total average seedling density and species composition, and like the aspen-birch community, this type shows a trend toward the fir-birch community of the mature forest.

Dewberry is the only low shrub of the community that is consistently present, although it is somewhat less important than in the aspen-birch community. The same species group is present here as in the aspen-birch type; however, total average cover is lower.

Large-leaf northern aster is again the most important member of the herbaceous class attaining its greatest cover and abundance in this type. Fewer species are present than in the previous community but the most important species are the same; e.g., wild sarsaparilla, false lily-of-the-valley, twin flower (*Linnaea borealis*), twisted stalk (*Streptopus roseus*), Clinton's lily, and grasses (table 6).

Mosses predominate in the moss-lichen class (table 6).

Table 6.--Summary of Frost Lake and Cherokee Lake wildfire areas birch plant community

Species and ground cover	Presence : in stands	Average frequency : in sample plots : within stands	Average : density	Average : basal : area	Average : cover	Average : relative : frequency	Average : relative : density	Average : relative : dominance	Average : importance : value	Commonness <sup>1/</sup> : index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<b>TREES</b>										
Betula papyrifera	100	98	2,458	54	--	62	79	63	68	9,813
Populus tremuloides	88	33	329	21	--	19	11	21	17	2,844
Abies balsamea	75	15	149	5	--	9	5	6	7	1,125
Sorbus americana	88	8	150	X	--	9	3	2	5	711
Picea glauca	63	6	44	1	--	4	1	2	2	352
Pinus banksiana	38	6	35	5	--	3	2	6	4	211
Pinus strobus	25	4	35	2	--	3	1	2	2	109
Picea mariana	13	1	8	X	--	1	X	X	X	16
<b>TALL SHRUBS</b>										
Corylus cornuta	100	29	2,613	2	-	28	49	61	46	2,938
Acer spicatum	88	28	1,125	X	--	22	19	16	19	2,461
Lonicera canadensis	88	11	816	X	--	9	15	7	10	968
Prunus pensylvanica	63	11	163	X	--	9	3	5	6	664
Amelanchier spp.	75	8	106	X	--	6	2	1	3	563
Salix bebbiana	63	8	113	X	--	8	2	4	5	469
Prunus virginiana	50	4	81	X	--	4	1	1	2	188
Cornus rugosa	50	4	200	X	--	3	3	1	2	188
Lonicera hirsuta	12	1	50	X	--	X	1	X	X	8
Alnus rugosa	12	1	133	X	--	X	X	X	X	8
<b>TREE SEEDLINGS</b>										
Abies balsamea	100	77	4,050	--	6	41	45	47	44	7,688
Betula papyrifera	100	66	3,225	--	3	36	46	32	38	6,563
Populus tremuloides	75	14	231	--	X	7	4	2	4	1,031
Picea glauca	88	11	119	--	1	6	2	11	6	930
Sorbus americana	88	8	150	--	X	4	2	1	2	711
Picea mariana	50	11	138	--	1	4	1	7	4	406
Thuja occidentalis	25	1	25	--	X	1	X	1	X	31
Acer rubrum	25	1	19	--	X	1	X	X	X	31
Pinus strobus	13	2	19	--	X	1	X	X	X	23
Pinus banksiana	13	1	6	--	X	X	X	X	X	8
<b>LOW SHRUBS</b>										
Rubus pubescens	100	26	--	--	1	61	--	50	56	2,563
Rubus strigosus	63	6	--	--	1	12	--	15	14	352
Rosa acicularis	75	3	--	--	X	7	--	9	11	234
Diervilla lonicera	50	3	--	--	1	8	--	14	11	156
Chimaphila umbellata	38	3	--	--	X	6	--	5	6	94
Ribes triste	13	1	--	--	X	1	--	X	1	16
Rubus parviflorus	13	1	--	--	X	1	--	6	4	8
Ribes spp.	13	1	--	--	X	3	--	1	2	8
Vaccinium angustifolium	13	1	--	--	X	1	--	X	1	8

#### Jack Pine-Birch Community

This community is the most complex of the four. The community summary (table 7) indicates a mixture of deciduous and coniferous canopy species. However, when the tree component of the 12 stands comprising the type is examined, three conditions emerge: (1) Jack pine is by far the most numerous tree in six stands, (2) paper birch is clearly more numerous in four stands, and (3) the two species are present in about equal numbers in two stands (table 8). In all three cases the birch are smaller in diameter which is reflected in the average basal area value for the type, birch contributing only 22 square feet of basal area in contrast to 112 square feet for jack pine (table 7). In those stands where jack pine is most numerous, there are generally fewer other associated tree species. Quaking aspen, balsam fir, and white spruce are important in those stands where birch is most numerous (table 8). Quaking aspen is much less prominent here than in the two previously described communities. While white spruce is important only in the stands where birch is important, it still

is most abundant as a tree in this community. Mountain-ash is also most abundant as a tree in this type.

The tall shrub class is not as well represented as in the two deciduous communities (table 7). Bebb willow is present in all but one stand and is most abundant with an average density of over 600 stems per acre and a basal area of 0.8 foot in this type. Beaked hazel, mountain maple, pincherry, and green alder, each absent in at least two stands within the type, are about equally important with 0.2 square foot of basal area each. Juneberry, squashberry (*Viburnum edule*), fly honeysuckle, and speckled alder are also present. This is the only community in which squashberry was found. Unlike the previously described communities, round-leaved dogwood is not represented.

Paper birch and balsam fir are the most conspicuous tree seedlings with average densities over 5,000 stems per acre, coverages of over 4 percent, and high indices of commonness (table 7). Both species are consistently present re-

Table 6 continued

Species and ground cover	Presence in stands	Average frequency in sample plots within stands	Average density	Average basal area	Average cover	Average relative frequency	Average relative density	Average relative dominance	Average importance value	Commonness <sup>1/</sup> index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<b>HERBACEOUS</b>										
<i>Aster macrophyllus</i>	100	83	--	--	30	26	--	66	46	8,313
<i>Aralia nudicaulis</i>	100	51	--	--	6	16	--	14	15	5,125
<i>Maianthemum canadense</i>	100	33	--	--	1	10	--	3	6	3,313
<i>Cornus canadensis</i>	100	31	--	--	3	8	--	7	8	3,125
Gramineae	100	31	--	--	1	9	--	1	5	3,063
<i>Linnaea borealis</i>	88	19	--	--	1	5	--	2	4	1,695
<i>Viola</i> spp.	75	13	--	--	X	4	--	X	2	984
<i>Galium triflorum</i>	88	9	--	--	X	3	--	1	2	820
<i>Streptopus roseus</i>	88	8	--	--	1	2	--	1	2	711
<i>Clintonia borealis</i>	75	9	--	--	1	2	--	2	2	656
<i>Aster ciliolatus</i>	88	7	--	--	X	2	--	1	1	602
<i>Trientalis borealis</i>	75	7	--	--	X	2	--	X	1	516
<i>Epilobium angustifolium</i>	75	6	--	--	X	2	--	X	1	469
<i>Lycopodium clavatum</i>	50	6	--	--	X	2	--	1	1	313
<i>Pyrola secunda</i>	50	5	--	--	X	1	--	X	1	250
Cyperaceae	63	4	--	--	X	1	--	X	1	234
<i>Anaphalis margaritacea</i>	75	3	--	--	X	1	--	X	1	188
<i>Goodyera repens</i>	38	4	--	--	X	1	--	X	1	141
<i>Lycopodium obscurum</i>	25	4	--	--	X	1	--	X	1	94
<i>Apocynum androsaemifolium</i>	38	3	--	--	X	1	--	X	X	94
<i>Coptis groenlandica</i>	38	3	--	--	X	1	--	X	1	94
<i>Actea rubra</i>	38	1	--	--	X	X	--	X	X	47
<i>Fragaria vesca</i>	25	1	--	--	X	1	--	X	X	31
<i>Anemone quinquefolia</i>	13	1	--	--	X	X	--	X	X	16
<i>Petasites palmatus</i>	13	1	--	--	X	X	--	X	X	16
<i>Lathyrus ochroleucus</i>	13	1	--	--	X	X	--	X	X	16
<i>Fragaria virginiana</i>	13	1	--	--	X	X	--	X	X	8
<i>Melampyrum lineare</i>	13	1	--	--	X	X	--	X	X	8
<i>Polypodium virginianum</i>	13	1	--	--	X	X	--	X	X	8
<i>Pyrola virens</i>	13	1	--	--	X	X	--	X	X	8
<i>Pteridium aquilinum</i>	13	*	--	--	X	--	--	X	X	--
<b>MOSS-LICHEN</b>										
Other mosses	100	79	--	--	3	21	--	3	12	7,938
Other lichens	100	66	--	--	1	17	--	2	9	6,563
<i>Calliergonella schreberi</i>	100	31	--	--	2	8	--	2	5	3,125
<i>Dicranum</i> spp.	100	15	--	--	X	4	--	X	2	1,500
<i>Cladonia rangiferina</i>	75	9	--	--	X	2	--	X	1	656
<i>Hylacomium splendens</i>	38	--	--	--	X	1	--	X	1	164
<i>Cladonia sylvatica</i>	38	3	--	--	X	1	--	X	X	94
<i>Hypnum crista-castrensis</i>	38	2	--	--	X	X	--	X	X	70
<b>GROUND CHARACTERISTICS</b>										
Litter	100	100	--	--	88	26	--	88	57	10,000
Dead wood	100	43	--	--	3	11	--	3	7	4,250
Live wood	100	16	--	--	X	4	--	X	2	1,625
Bare rock	75	9	--	--	1	2	--	1	2	656
Bare ground	13	1	--	--	X	X	--	X	X	16

X denotes values of less than one percent.

\* indicates a species value for ground cover but no rooted frequency of occurrence in the sample plots.

<sup>1/</sup> The commonness index is not always an exact product of presence and frequency here because these two factors were rounded for this table after the commonness index was determined.

ardless of whether jack pine or paper birch is most numerous in the canopy. Black spruce is present in all but one stand and has considerable average ground cover (3.6 percent) of larger but fewer individuals (850 stems per acre). A lower average density (150 stems) and cover (0.8 percent) characterizes white spruce seedlings, and they occur in only eight of the 12 stands. Less important are quaking aspen, mountain-ash, white-cedar, white pine, red maple, and jack pine. While not very common in any of the four communities, mountain-ash, white spruce, and white pine seedlings reach greatest abundance here (table 7). The future of this type is likely to be more complex than that of the aspen-birch and birch communities. However, the presence of balsam fir, paper birch, and black spruce seedlings indicates the same trend to fir-birch with a relative increase in the importance of black spruce, especially in those stands dominated by jack pine.

Bush honeysuckle is the most important species of the poorly represented low shrub group.

It is present in 10 of the 12 stands with about 2 percent average cover. The rest of the low shrub group of species is much the same as in the previous two communities but is more poorly represented with only dewberry present in at least half the stands (table 7).

This community exhibits only about half the herbaceous cover of the other three communities. Based on the commonness index (table 7), this is the only one of the four types in which large-leaf northern aster is clearly not the most common herb. It occurs in all but one stand of the type and is the major cover in four of the stands, yet it is less important here than in the other three types. The most common species is bunchberry followed by the aster, with false lily-of-the-valley, twin-flower, and wild sarsaparilla among the most important of the 33 species encountered. Sweet bedstraw and grasses are notably less important in this type than in the others.

Table 7.--Summary of Frost Lake and Cherokee Lake wildfire areas jack pine-birch plant community

Species and ground cover	Presence : in stands	Average frequency : in sample plots : within stands	Average : density	Average : basal : area	Average : cover	Average : relative : frequency	Average : relative : density	Average : relative : dominance	Average : importance : value	Commonness <sup>1/</sup> : index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<u>TREES</u>										
Betula papyrifera	100	70	1,388	22	--	41	41	19	34	7,000
Pinus banksiana	100	67	1,450	112	--	41	48	68	53	6,708
Sorbus americana	67	13	254	X	--	14	12	9	12	889
Abies balsamea	67	8	93	4	--	5	3	3	4	556
Populus tremuloides	58	9	86	6	--	5	2	4	4	535
Picea glauca	33	8	118	5	--	4	3	5	4	278
Picea mariana	42	6	60	1	--	4	2	1	2	260
Pinus strobus	8	1	3	X	--	X	X	X	X	4
<u>TALL SHRUBS</u>										
Salix bebbiana	83	21	646	1	--	25	30	38	31	1,736
Corylus cornuta	83	11	496	X	--	17	19	16	17	938
Amelanchier spp.	83	11	217	X	--	14	11	11	12	903
Acer spicatum	75	11	371	X	--	13	13	8	11	813
Prunus pensylvanica	83	10	154	X	--	12	7	13	11	799
Lonicera canadensis	42	2	54	X	--	3	2	1	2	87
Alnus crispa	17	2	92	X	--	2	4	4	3	28
Viburnum edule	8	1	92	X	--	X	1	X	1	7
Alnus rugosa	8	1	8	X	--	1	1	X	X	4
<u>TREE SEEDLINGS</u>										
Abies balsamea	100	78	5,142	--	4	37	42	31	37	7,750
Betula papyrifera	100	68	5,879	--	5	32	40	31	34	6,750
Picea mariana	92	36	850	--	4	16	9	28	18	3,285
Sorbus americana	67	13	254	--	X	5	3	1	3	889
Picea glauca	67	9	150	--	1	3	1	6	4	583
Populus tremuloides	42	6	275	--	X	2	2	1	2	260
Acer rubrum	33	3	25	--	X	1	X	X	1	83
Pinus banksiana	33	2	17	--	X	1	X	1	1	56
Pinus strobus	33	2	29	--	X	1	1	X	1	56
Thuja occidentalis	17	2	92	--	X	1	2	X	1	35
<u>LOW SHRUBS</u>										
Diervilla Lonicera	83	9	--	--	2	25	--	46	36	764
Rubus pubescens	67	7	--	--	X	21	--	16	18	472
Chimaphila umbellata	67	6	--	--	X	18	--	20	23	417
Vaccinium myrtilloides	42	5	--	--	X	17	--	10	13	208
Rubus strigosus	33	2	--	--	X	7	--	4	5	69
Rosa acicularis	25	2	--	--	X	3	--	3	3	52
Vaccinium angustifolium	17	1	--	--	X	1	--	1	1	14
Ribes glandulosum	8	1	--	--	X	1	--	X	X	4
Ribes spp.	8	*	--	--	X	--	--	X	X	--

Although mosses dominate the moss-lichen stratum, lichens (other than the *Cladonia* species) are the most common (table 7). This stratum has about the same percent cover as the jack pine community type--about double that of the two deciduous communities.

#### Jack Pine Community

The jack pine community has a tree stratum clearly dominated by jack pine which has an average density of 1,157 stems and 145 feet of basal area per acre (table 9). Paper birch, quaking aspen, and black spruce are present, but their combined basal area is only about one-tenth that of the jack pine. No other species of trees were encountered in the four stands comprising the type. Compared with the other types, the tree stratum has the lowest average density, 1,575 stems per acre, and yet the highest basal area, 160 square feet per acre. This is probably indicative of a general even growth of the numerous jack pine.

Beaked hazel with an average density of 1,575 stems and 0.8 square foot of basal area

clearly dominates the shrub stratum (table 9). Green alder and pincherry also have appreciable average basal area, 0.7 and 0.3 square foot, respectively, but average only about 300 stems per acre. Other members of this stratum are bebb willow, mountain maple, juneberry, fly honeysuckle, and chokecherry. Like the jack pine-birch community, this type has a sparse tall shrub stratum with a total average density of 3,163 stems and only 2.3 square feet of basal area per acre. A lesser tall shrub component in coniferous community types was also noted in the mature upland communities of the BWCA (Ohmann and Ream 1971b).

The tree seedling class is characterized by the lack of significant numbers of balsam fir. In contrast to the other three types, it has an average of only 25 stems per acre, and fir occurred in only one of the four stands comprising the type. Paper birch is the only common seedling with an average density of 2,638 stems and an average cover of 1 percent (table 9). The larger but less common black spruce seedlings also have 1 percent cover but are present in only three of the four stands. Other

Table 7 continued

Species and ground cover	Presence in stands	Average frequency in sample plots within stands	Average density	Average basal area	Average cover	Average relative frequency	Average relative density	Average relative dominance	Average importance values	Commonness <sup>1/</sup> index
	Percent	Percent	Stems per acre	Sq. ft. per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<b>HERBACEOUS</b>										
Cornus canadensis	92	48	--	--	6	19	--	26	23	4,354
Aster macrophyllus	92	32	--	--	7	17	--	32	25	2,941
Maianthemum canadense	100	25	--	--	1	11	--	6	9	2,542
Linnaea borealis	75	33	--	--	3	12	--	10	11	2,438
Aralia nudicaulis	75	16	--	--	2	8	--	7	8	1,188
Goodyera repens	83	6	--	--	X	3	--	1	2	486
Viola spp.	58	8	--	--	X	3	--	1	2	438
Gramineae	58	5	--	--	X	2	--	1	2	316
Clintonia borealis	50	6	--	--	1	2	--	2	2	292
Trientalis borealis	50	5	--	--	X	2	--	X	1	229
Epilobium angustifolium	58	4	--	--	X	3	--	4	3	219
Fragaria vesca	50	4	--	--	X	2	--	1	1	188
Pyrola secunda	50	4	--	--	X	2	--	1	1	188
Cyperaceae	50	3	--	--	X	2	--	1	1	167
Streptopus roseus	42	3	--	--	X	1	--	1	1	139
Galium triflorum	33	3	--	--	X	1	--	X	1	83
Lycopodium clavatum	25	3	--	--	1	1	--	2	1	73
Pyrola virens	25	1	--	--	X	1	--	X	X	31
Petasites palmatus	17	2	--	--	X	1	--	X	1	28
Lycopodium obscurum	17	1	--	--	X	X	--	X	X	21
Anemone quinquefolia	17	1	--	--	X	X	--	X	X	14
Coptis groenlandica	17	1	--	--	X	X	--	X	X	14
Pyrola elliptica	17	1	--	--	X	1	--	X	X	14
Lycopodium annotinum	8	1	--	--	X	1	--	1	1	10
Aster ciliolatus	8	1	--	--	X	1	--	X	X	10
Goodyera tessellata	8	1	--	--	X	X	--	X	X	7
Dryopteris spinulosa	17	1	--	--	X	X	--	X	X	7
Equisetum spp.	17	1	--	--	X	X	--	X	X	7
Fragaria virginiana	8	1	--	--	X	X	--	1	1	7
Lycopus spp.	8	1	--	--	X	X	--	X	X	7
Waldsteinia fragarioides	8	1	--	--	X	X	--	X	X	4
Lathyrus ochroleucus	8	1	--	--	X	X	--	X	X	4
Antennaria neodioca	8	1	--	--	X	1	--	2	1	4
Moneses uniflora	8	1	--	--	X	1	--	1	1	4
Mitella nuda	8	1	--	--	X	X	--	X	X	4
Melampyrum lineare	8	1	--	--	X	X	--	X	X	4
<b>MOSS-LICHEN</b>										
Other lichens	100	80	--	--	2	16	--	2	9	8,000
Other mosses	100	75	--	--	3	15	--	3	9	7,458
Calliergonella schreberi	100	64	--	--	7	13	--	7	10	6,375
Polytrichum spp.	100	43	--	--	2	9	--	2	5	4,333
Dicranum spp.	100	37	--	--	1	7	--	1	4	3,667
Gadonia rangiferina	92	26	--	--	1	5	--	X	3	2,406
Gadonia sylvatica	67	7	--	--	X	1	--	X	1	444
Hypnum crista-castrensis	75	6	--	--	X	1	--	X	1	438
Hylacomium splendens	25	2	--	--	X	X	--	X	X	42
<b>GROUND CHARACTERISTICS</b>										
Litter	100	100	--	--	78	20	--	79	49	9,958
Dead wood	100	43	--	--	4	8	--	4	6	4,250
Live wood	92	23	--	--	1	4	--	1	3	2,101
Bare rock	58	7	--	--	1	1	--	1	1	413
Bare ground	17	1	--	--	X	X	--	X	X	14

X denotes values of less than one percent.

\* indicates a species value for ground cover but no rooted frequency of occurrence in the sample plots.

<sup>1/</sup> The commonness index is not always an exact product of presence and frequency here because these two factors were rounded for this table after the commonness index was determined.Table 8.--A comparison of the density of tree species in the jack pine-birch plant community in relation to the numerical dominance of jack pine or paper birch in the individual stands of the community<sup>1/</sup>

Species	Stands numerically dominated by		
	Jack pine	Paper birch	Jack pine and birch
Quaking aspen	3	193	120
Paper birch	558	2,774	1,108
Jack pine	2,268	226	1,443
Balsam fir	21	143	68
White spruce	5	347	--
Black spruce	59	61	--

<sup>1/</sup> Density in stems per acre.

Constituents of the seedling stratum are mountain-ash, red maple, quaking aspen, white-barked, and jack pine, but they occurred in only one stand within the type. The total average seedling density of 2,975 stems per acre and

cover of 2.4 percent are considerably below those of the other community types.

Low shrubs are not well represented; the highest index of commonness is well below 500 (table 9). No species dominates this stratum, although red raspberry and wild rose are the most important. Perhaps indicative of the more xeric conditions in this type is the presence of low juniper (*Juniperus communis*), found only here.

The herbaceous stratum contains fewer members than in the other communities, but the dominants are much the same with large-leaf northern aster, wild sarsaparilla, bunchberry, and false lily-of-the-valley being the most important (table 9).

Lichens and mosses are both common in the moss-lichen category (table 9). Although the total average cover for the mosses exceeds that

Table 9.--Summary of Frost Lake and Cherokee Lake wildfire areas jack pine plant community

Species and ground cover	Presence in stands	Average frequency in sample plots within stands	Average density	Average basal area	Average scrub	Average relative frequency	Average relative density	Average relative dominance	Average commonness value	1 commonness index
	Percent	Percent	Sq. ft. Per plot	Sq. ft. Per acre	Percent	Percent	Percent	Percent	Percent	Presence X frequency
<u>TREES</u>										
Pinus banksiana	100	95	1,157	140	--	52	64	94	89	9,500
Betula papyrifera	100	54	273	34	--	8	20	6	18	5,250
Populus tremuloides	100	10	105	13	--	15	13	4	10	3,000
Sorbus americana	100	9	150	18	--	11	6	7	8	875
Picea mariana	75	11	40	5	--	6	4	1	4	844
<u>TALL SHRUBS</u>										
Corylus cornuta	100	10	1,575	1	--	3	49	44	42	3,000
Amelanchier spp.	100	13	250	X	--	14	10	4	9	1,250
Salix bebbiana	100	13	313	X	--	13	9	11	11	1,250
Acer spicatum	75	14	325	X	--	15	13	10	13	1,031
Prunus pensylvanica	50	6	213	X	--	6	4	9	6	313
Lonicera canadensis	50	3	100	X	--	3	4	5	4	125
Alnus crispa	25	3	375	1	--	3	6	12	7	63
Prunus virginiana	25	1	13	X	--	2	X	X	1	31
<u>TREE SEEDLINGS</u>										
Betula papyrifera	75	40	2,638	--	1	45	66	37	49	3,000
Picea mariana	75	9	88	--	1	9	2	26	13	656
Sorbus americana	75	6	75	--	X	7	2	3	4	469
Acer rubrum	50	5	50	--	X	7	2	3	4	250
Abies balsamea	25	3	25	--	X	2	X	1	1	63
Populus tremuloides	25	3	38	--	X	4	2	5	4	63
Thuja occidentalis	25	1	25	--	X	1	X	1	1	31
Pinus banksiana	25	1	38	--	X	1	1	1	1	31
<u>LOW SHRUBS</u>										
Rubus strigosus	75	5	--	--	X	27	--	12	19	375
Rosa acicularis	50	4	--	--	X	31	--	27	29	188
Chimaphila umbellata	50	3	--	--	X	15	--	7	11	125
Rubus pubescens	25	3	--	--	X	13	--	15	14	63
Vaccinium myrtilloides	25	1	--	--	X	8	--	13	11	31
Juniperus communis	25	1	--	--	X	6	--	14	10	31
Diervilla lonicera	50	*	--	--	X	--	--	13	6	--
<u>HERBACEOUS</u>										
Aster macrophyllus	100	74	--	--	13	29	--	47	38	7,375
Aralia nudicaulis	100	55	--	--	12	22	--	23	22	5,500
Cornus canadensis	100	36	--	--	5	14	--	11	13	1,625
Maianthemum canadense	100	24	--	--	2	10	--	5	7	2,375
Lycopodium clavatum	75	14	--	--	2	5	--	4	4	1,031
Gramineae	75	11	--	--	1	4	--	2	3	844
Linnaea borealis	75	8	--	--	1	3	--	3	3	563
Goodyera repens	75	5	--	--	X	2	--	X	1	375
Trientalis borealis	75	4	--	--	X	2	--	X	1	281
Galium triflorum	50	5	--	--	X	2	--	X	1	250
Polygonum cilinode	50	3	--	--	X	1	--	X	1	125
Coptis groenlandica	50	3	--	--	X	1	--	X	1	125
Pteridium aquilinum	25	4	--	--	1	2	--	2	2	94
Streptopus roseus	50	1	--	--	X	1	--	X	X	63
Pyrola virens	25	3	--	--	X	1	--	X	1	63
Anaphalis margaritacea	25	3	--	--	1	1	--	2	1	63
Pyrola elliptica	25	1	--	--	1	1	--	1	1	31
Viola spp.	25	1	--	--	X	1	--	X	1	31
Cyperaceae	25	1	--	--	X	1	--	X	X	31
Corallorhiza maculata	25	1	--	--	X	1	--	X	1	31
Pyrola secunda	25	1	--	--	1	1	--	X	X	31
Clintonia borealis	25	*	--	--	--	--	--	--	--	--
Epilobium angustifolium	25	*	--	--	--	--	--	--	--	--
Apocynum androsaemifolium	25	*	--	--	--	--	--	1	X	--
<u>MOSS-LICHEN</u>										
Other lichens	100	86	--	--	4	20	--	4	12	8,625
Other mosses	100	83	--	--	5	19	--	5	12	8,250
Polytrichum spp.	100	36	--	--	1	9	--	1	5	3,625
Calliergonella schreberi	100	28	--	--	X	6	--	4	4	2,750
Cladonia rangiferina	75	28	--	--	X	6	--	1	3	2,063
Dicranum spp.	100	20	--	--	1	4	--	1	3	2,000
Cladonia sylvatica	25	3	--	--	1	1	--	1	1	63
Hypnum crista-castrensis	25	1	--	--	X	--	--	X	--	31
<u>GROUND CHARACTERISTICS</u>										
Litter	100	100	--	--	36	74	--	5	52	10,000
Dead wood	100	38	--	--	--	4	--	--	--	3,750
Bare rock	75	13	--	--	1	--	--	2	--	938
Live wood	31	4	--	--	--	--	--	1	1	438

X denotes values of less than one percent.

\* indicates a species value for ground cover but no recorded frequency or commonness in the sample plots.

1/ The commonness index is not always an exact product of presence and frequency here because these two factors were rounded for this table after the commonness index was determined.

of the lichens, the ratio of lichen cover to moss cover is higher here than in any of the other three types. This is also probably indicative of the more xeric nature of this type.

### Environmental Parameters

Environmental factors are highly interrelated with each other and vegetation (Billings 1952), but it is useful to examine as many individual measures as possible. Of the general parameters--

elevation, slope, position on slope, distance to water, and annual insolation, only elevation is significantly different among the four community types (fig. 5). This difference can be explained by the fact that the Frost Lake area is generally lower in elevation than the Cherokee Lake area and because all the birch community stands are from the Frost Lake burn while the stands composing the other types are either from the Cherokee burn area or from both areas.

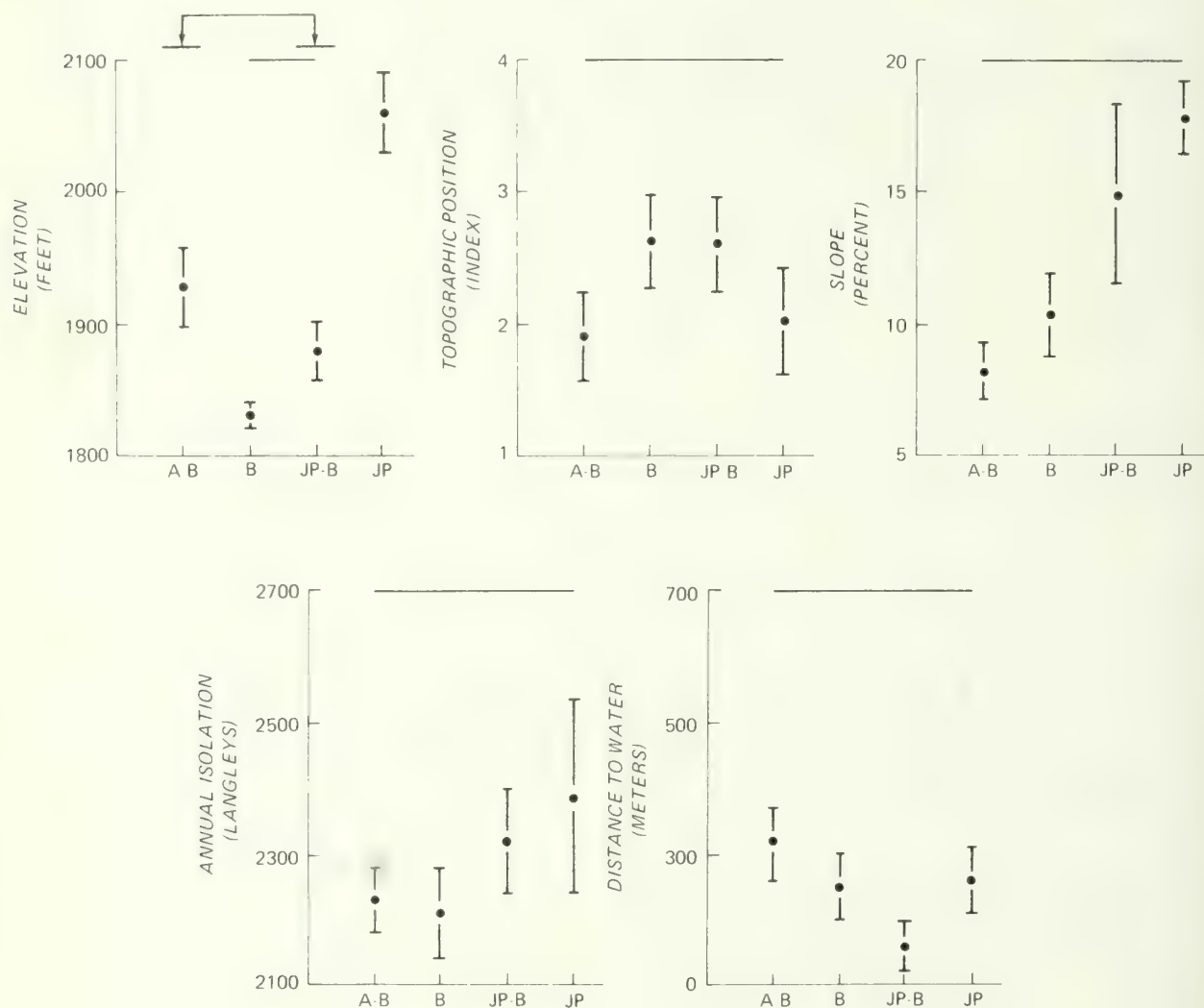


Figure 5.--Means and standard errors of means of general environmental parameters measured in community types from Frost Lake and Cherokee Lake wild-fire areas. A-B, B, JP-B, and JP refer to aspen-birch, birch, jack pine-birch, and jack pine community types, respectively. Elevation in feet above sea level. Topographic position index based on 1 = ridgetop, 2 = upper slope, 3 = mid-slope, 4 = lower slope, and 5 = valley. Slope in percent based on an average of five readings taken within each stand. Total possible annual insolation in Langley's based on aspect and slope as determined from appropriate tables in Frank and Lee (1966). Distance to nearest body of water over 5 acres in meters. Any two means not connected by a line are significantly different ( $P = 0.05$ ).

Most of the significant differences in soil characteristics are between the birch and the jack pine community types (figs. 6, 7, and 8). In summary, the birch type representing part of the Frost Lake burn area is lower in elevation, and the B-soil horizon is lower in available water, percent silt, and nitrogen, and is higher in percent total and coarse sand, total and percent bases, and calcium. The jack pine community, as representative of part of the Cherokee Lake burn area, is higher in elevation, and lower in percent bases while high in CEC, nitrogen, hydrogen, and potassium in the B-horizon soils. Within the Cherokee Lake area there are few differences between community types, with the aspen-birch community lower in CEC, hydrogen, and potassium than the jack pine community.

### Preburn Vegetation

Two photo interpretations of the vegetation on sample locations were conducted on 1934 aerial photographs. One interpretation indicated only the major tree cover on those sample locations where stereo-photographic coverage was available (table 10, col. 2). Another interpretation in-

cluded, in addition to the major tree cover, an estimate of whether the cover was of old or young growth, and an estimate of the degree of canopy cover over each sample point. The results of this interpretation are presented in the last three columns of table 10.

The stands of the aspen-birch and birch community types were interpreted as comprised of rather old open-grown broadleaf forest in 1934, 2 years before the wildfire. The stands of the jack pine-birch community type were classified as some combination of moderately dense to dense jack pine with some broadleaf component, and the stands of the jack pine type were classified as rather young dense jack pine before the fire.

The presence of old, open growth is verified by the narrative reports accompanying the 1936 individual fire reports for both fires. The reports emphasize that much of the areas had been subjected to insect and wind disturbance before the fires; e.g., "This area is quite hazardous, very brushy, with balsam reproduction and a lot of dead and down balsam" and "...burning in an old timber type and the ground very

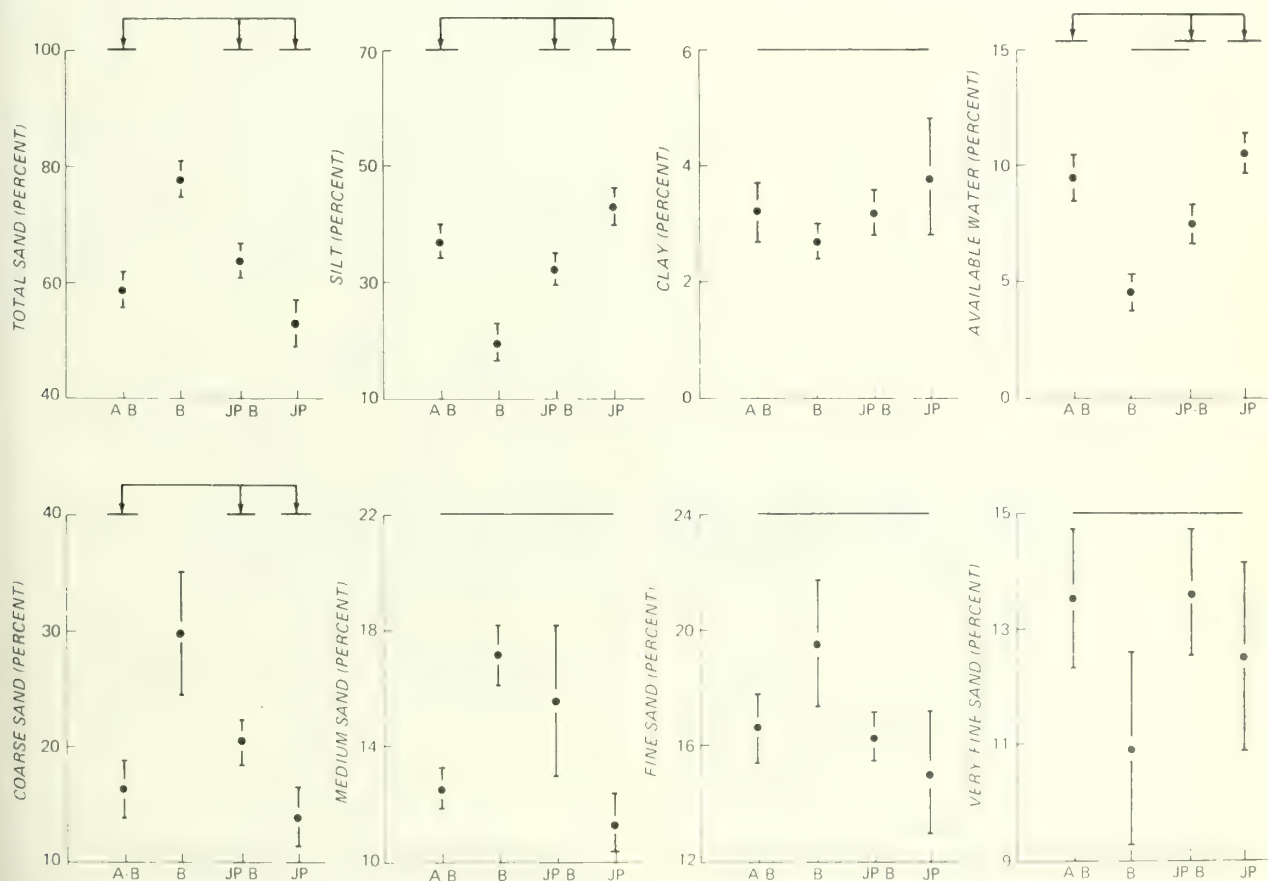


Figure 6.--Means and standard errors of means for B-horizon soil particle size and available water characteristics of plant communities of the Frost Lake and Cherokee Lake wildfire areas. All values are in percent. Significance of difference in means as indicated in figure 5.

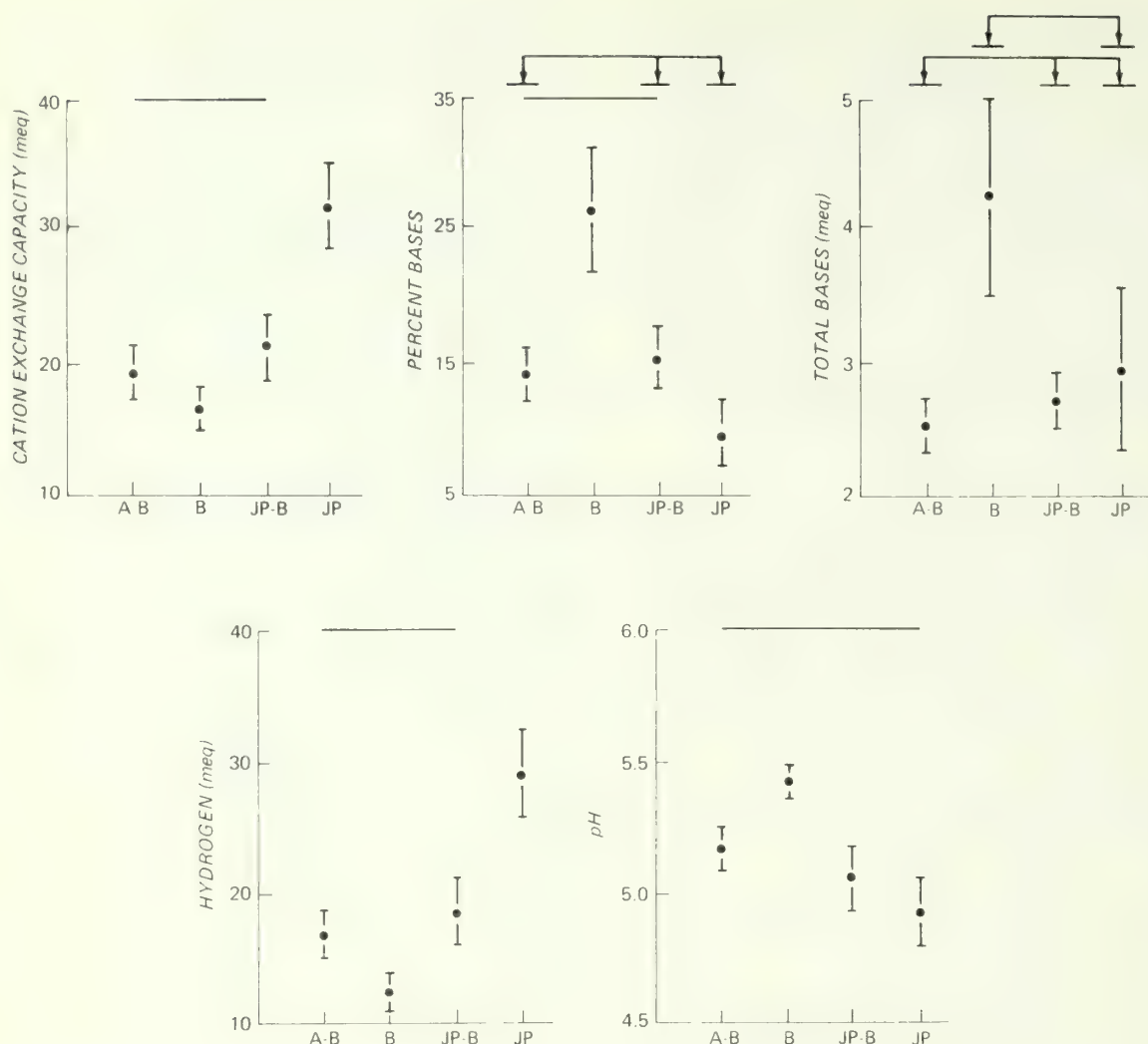


Figure 7.--Means and standard errors of means for B-horizon soil cation exchange capacity, percent bases, total bases, hydrogen ion concentration, and pH for plant communities of the Frost Lake and Cherokee Lake wildfire areas. Values in percent or milliequivalents (meq) as indicated. Significance of difference in means as indicated in figure 5.

heavily covered with insect killed blowdown timber mixed with brush and balsam undergrowth."

No doubt the variation in canopy cover and the age of the stands influenced fire intensity which in turn affected the resulting revegetation of the two areas. The presence of young dense jack pine before burning is apparently positively related to the present jack pine stands, and certain of the jack pine-birch stands. There is also a relationship between cover type, greater age, degree of canopy cover prior to burning, and the present aspen-birch and birch stands. To illustrate the relationship between the 1934 preburn vegetation type and the postburn vegetation, a portion of the

Cherokee Lake area is portrayed in figure 9. Note the occurrence of present jack pine forest in areas of former young, dense, coniferous growth.

## CONCLUSIONS

The virgin plant communities of intermediate age are much more limited in type, at least over this 6,000-acre area, than those of the mature virgin forest where succession operating over longer and varied periods of time has produced a wide variety of recognizable types (Ohmann and Ream 1971b).

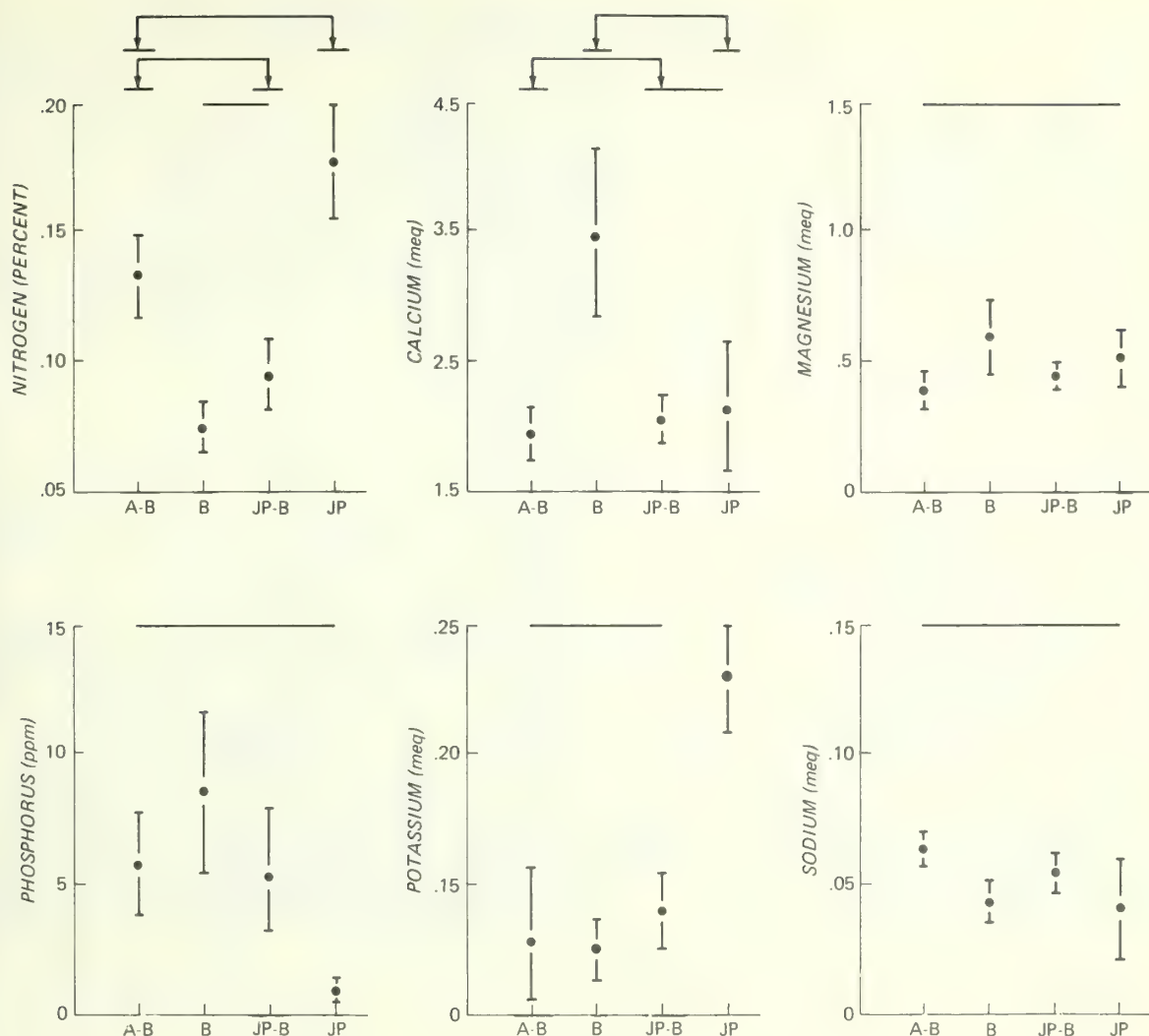


Figure 8.--Means and standard errors of means of B-horizon soil nutrients for plant communities of the Frost Lake and Cherokee Lake wildfire areas. Values in parts per million (ppm), percent, or milliequivalents (meq) as indicated. Significance of differences in means as indicated in figure 5.

Time elapsed since last major disturbance is important in determining community composition and structure, but this study indicates that the composition and structure of the community at the time of disturbance is also an important factor.

There are some environmental differences between community types that may be affecting composition and structure--birch type on coarser sands and jack pine on finer sands; however, some of those found make little sense ecologically, and others may well be reflecting the vegetation on the site now and even perhaps in the past as much as the site and soils themselves.

For example, particle size is a basic physical property of soil and can therefore be expected to have an influence on the vegetation capable of occupying the site. The relationship present between the vegetation types of this study and the physical properties of the soils is unexpected. Normally jack pine is more likely than birch to be found on the coarser textured soils with lower water-holding capacity.

Contrary to physical properties, soil chemical properties are not independent of vegetation and partially reflect the vegetation type occupying the site. A higher CEC would normally

Table 10.--Sample point vegetation interpretation from 1934  
aerial photographs of the Frost Lake and Cherokee Lake  
wildfire areas

Community type : Interpretation 1 :		Interpretation 2		
stand number :	type <sup>1/</sup> :	Type <sup>1/</sup> :	Maturity :	Canopy cover
Aspen-birch				
1	A-JP	JP some A	Old	Moderately open
2	A	A	Old	Very open
3	A	A	Old	Very open
4	A-JP	JP-A	Old	Moderately open
5	A-JP	A	Old	Moderately open
6	A-JP	A some JP	Old	Moderately open
7	A	A	Old	Open
9	A	A some JP	Young	Dense
25	JP	JP some A	Old	Dense
Birch				
22	A	A with scattered tall spruce	Old	Open
23	A	do.	Old	Open
24	A	do.	Old	Open
30	A-JP	A	Old	Open
31	JP-A	A some JP	Old	Very open
32	A	A	Old	Very open
33	A	A	Old	Very open
34	A	A	Old	Very open
Jack pine-birch				
10	JP	JP	Young	Dense
12	A	A some JP	Young	Moderately dense
13	A	A with scattered tall pine and spruce	Young	Dense
14	--	--		
15	--	--		
20	A	A	Young	Dense
21	A	A	Old	Open
26	A	JP some A	Old	Moderately open
27	JP	JP some A?	Old	Moderately dense
28	JP	JP some A?	Old	Moderately dense
29	A	JP some A	Old	Moderately open
35	--	--		
Jack pine				
11	--	JP	Young	Dense
16	A	A with scattered pine and spruce (near an area of dense young JP)	Old	Very open
17	--	JP	Young	Dense
18	--	JP	Young	Dense

<sup>1/</sup> Type "A" indicates predominance of broadleaf tree species mostly quaking aspen, paper birch, or both--although other broadleaf species might be present. Type "JP" indicates coniferous species--usually jack pine, although other conifers may also be present.

be expected in finer-textured soils (occupied by the jack pine community) than in coarser-textured soils (occupied by the birch community) but bases would not be expected to be recycled as readily by jackpine as by birch. Thus much of the soil CEC in the jack pine type is likely occupied by exchangeable hydrogen, which is also indicated by the lower pH. Although there is a lower soil CEC under the birch type, more bases are likely being recycled resulting in a higher base saturation (especially calcium) and therefore, a higher pH.

We do not have a measure of the total potassium in the system within any of the community types (we don't know how much is tied up in the vegetation). The higher potassium in the soils of the jack pine type could be reflecting the lesser requirement of potassium by the coniferous jack pine cover thus leaving a greater potassium residual than in the soils under the birch cover type.

Thus, we feel the results of this study, while not conclusive, tend to support the hypothesis advanced by Ohmann and Ream (1971b) that time elapsed since last major disturbance and the type of vegetation present at the time of that disturbance are more important in determining the composition and structure of the present upland plant communities over a relatively small region than differences in environmental parameters.

These generalizations, of course, are oversimplified. In fact, many other factors ought to be considered if they could be determined, especially severity of the fire, presence of seed source following fire, postfire weather conditions, etc. It should also be recognized that these generalizations are not meant to apply to the quality of the vegetation (e.g., site index, productivity, biomass, etc.) where we recognize that differences in environment are more important.

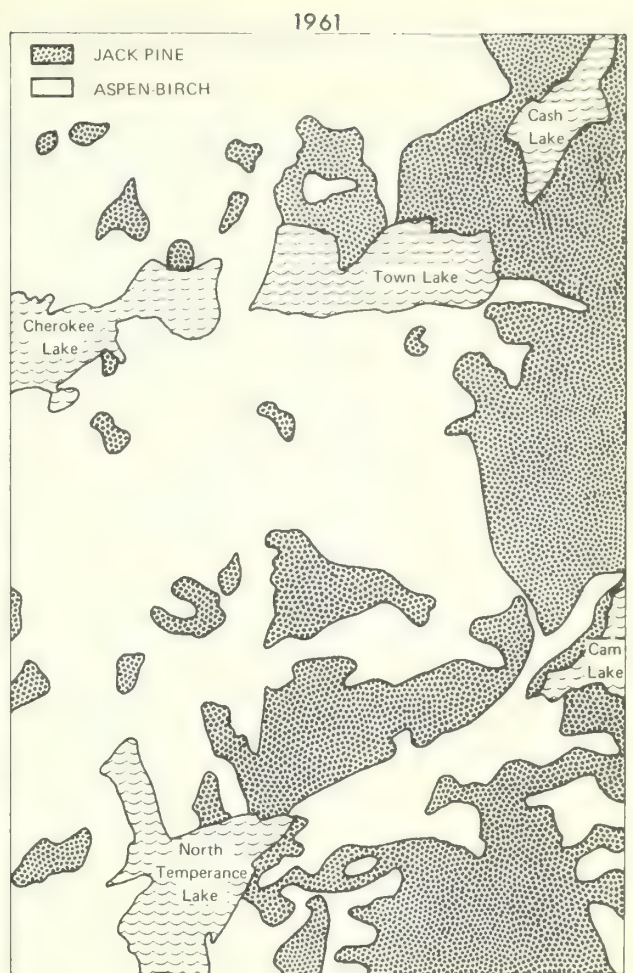
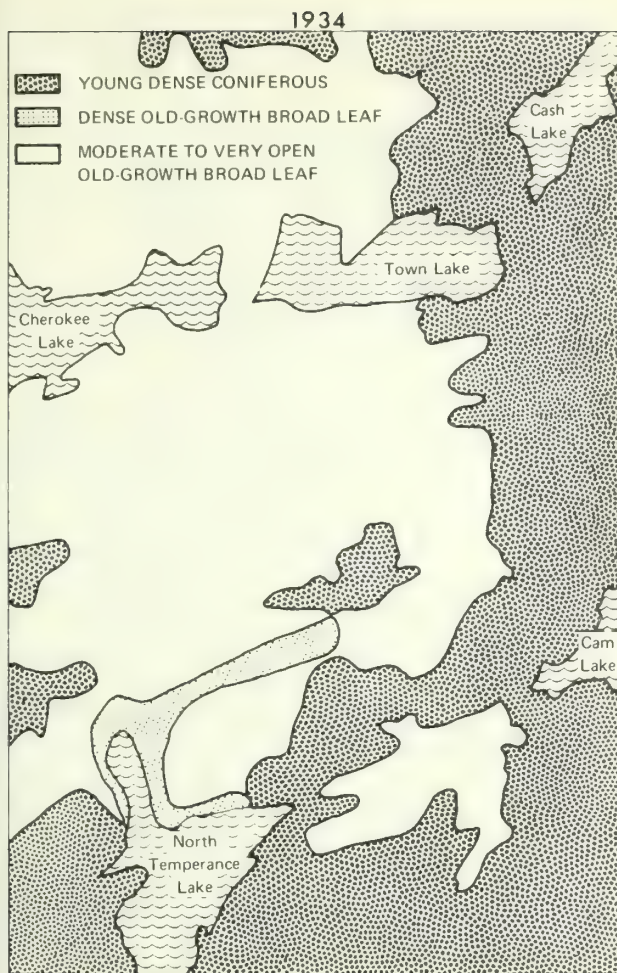


Figure 9.--Location (left) of 1934 vegetative cover on a portion of the Cherokee Lake wildfire area. Location (right) of 1961 vegetative cover on the same area.

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## PART II. BROWSE PRODUCTION

Roger E. Lake

### ABSTRACT

Woody browse production was measured in four upland community types on two adjacent 33-year-old wildfire areas. No difference in twig numbers were found between the burns for ten species studied. Only three of the ten browse species present in more than one community type showed differences in twig numbers among the types. Yields of the species groups, total shrub browse, and total tree seedling browse, differed among the types while total browse did not. Lack of a difference in total browse production is attributed to various species reaching peak yield in different community types, thus offsetting each other and maintaining an overall relatively stable level of production.

### RESULTS

Total browse production was similar but highly variable on the two burn areas, with an average of 199,220 twigs per acre at Cherokee Lake and 256,080 at Frost Lake (table 1). Ten

Table 1.--Browse production on two 33-year-old wildfire areas by species, total tree seedlings, total shrubs, and total browse

(In twigs/acre with  $\pm 95$  percent confidence limits)<sup>1/</sup>

Species	Cherokee Lake Area	Frost Lake Area
<i>Abies balsamea</i>	55,640	164,100
	+53,508	+159,727
	74,550	26,260
	+48,907	+19,221
	10,420	38,740
	+12,564	+35,162
	16,450	3,600
	+13,020	+4,751
<i>Salix bebbiana</i>	9,340	12,600
	+6,851	+14,690
	2,940	2,550
	+4,288	+5,180
	2,040	2,710
	+3,983	+4,143
	2,310	1,950
	+2,552	+2,554
	50	1,000
	+100	+1,743
	220	100
	+317	+213
<i>Thuja occidentalis</i>	20,090	
	+30,738	
	5,050	
	+10,700	
<i>Pinus strobus</i>		2,240
		+3,974
		230
		+479
<i>Viburnum edule</i>	120	
	+249	
	10	
	+25	
Total tree seedlings	86,440 <sup>2/</sup>	206,180
	+76,760	+169,615
Total shrubs	112,790 <sup>3/</sup>	49,900 <sup>3/</sup>
	+56,705	+24,186
Total browse	199,220	256,080
	+83,744	+111,111

1/ Numbers of twigs per acre in total length occurring between 6 inches and 10 feet of the ground.

2/ Due to rounding errors, columns may not total exactly.

3/ Indicates a significant difference between areas at

The study was conducted as an adjunct to the ecological study described in Part I. The objectives were to estimate browse production and to determine if it differed between burn areas and their plant communities.

The study area had never been logged, grazed, or farmed. There is an absence of data on browse production in such "natural" plant communities, but this may not be real in that most authors have not mentioned this distinction. Studies reporting on browse production in upland forests of the northeastern United States include Crawford and Leonard (1963), Dalke (1941), Krefting and Hansen (1969), Segelquist and Green (1968), and Shaw and Ripley (1965). These studies all indicate possible differences in browse production among cover types but present no statistical comparisons. Zieciolowski (1969) found that seven Polish forest associations could be placed into two homogeneous groups which differed significantly in browse production. Segelquist and Pennington (1968, 1972) in Oklahoma and Arkansas reported no significant differences in browse yields among timber types. Only the study by Krefting and Hansen (1969) was conducted in community types similar to those of this study area.

### METHODS

Browse was sampled in five milacre plots randomly selected from among the 20 shrub and seedling plots per stand. Twigs were counted that were greater than 1 inch in total length, occurred between 6 inches and 10 feet of the ground, and originated from stems rooted within the plot. White and black spruce (*Picea glauca* and *P. mariana*, respectively) were not sampled since no browsing of these species was noted.

Differences in browse production between burn areas and among community types were identified by using a series of t- and F-tests. The procedure consisted of checking for homogeneity of variances and then using the appropriate t- or F-test (Sokal and Rohlf 1969, Steel and Torrie 1960).

Names for tree species follow Little (1953) and for shrub species, Gleason (1963).

browse species were found on both burn areas. A series of t-tests showed that none of their mean numbers of twigs per acre differed at  $P = 0.05$  between burn areas. When the data were grouped as total tree seedling browse, total shrub browse, and total browse, only total shrub browse showed a difference at  $P = 0.05$  between burn areas (table 1).

Browse production by community type is presented in table 2. A series of F-tests indicated that only three species, beaked hazel (*Corylus cornuta*), paper birch (*Betula papyrifera*), and mountain maple (*Acer spicatum*), as well as the two characters' total tree seedling browse and total shrub browse, differed (at  $P = 0.05$ ) in production among community types.

Table 2.--Browse production in the 33-year-old upland community types of the Cherokee-Frost Lake study area  
(In twigs/acre with  $\pm 95$  percent confidence limits)<sup>1/</sup>

Species	Community type				Significance level <sup>2/</sup>
	Aspen-birch	Birch	Jack pine-birch	Jack pine	
<i>Abies balsamea</i>	39,730 $\pm 55,204$ <sup>3/</sup>	244,030 $\pm 333,567$	105,130 $\pm 91,195$		$P = ns$
<i>Corylus cornuta</i>	95,470 <sup>a</sup>	43,330 <sup>a,b</sup>	6,150 <sup>b</sup>	102,000 <sup>a,b</sup>	$P = 0.050$
	$\pm 67,140$	$\pm 35,145$	$\pm 10,000$	$\pm 214,578$	
<i>Betula papyrifera</i>	8,800 <sup>a,b</sup>	22,400 <sup>a</sup>	44,200 <sup>a,b</sup>	2,050 <sup>b</sup>	$P = 0.050$
	$\pm 15,240$	$\pm 16,142$	$\pm 49,504$	$\pm 6,523$	
<i>Acer spicatum</i>	28,270 <sup>a</sup>	7,130 <sup>a,b</sup>	2,120 <sup>b</sup>	100 <sup>b</sup>	$P = 0.050$
	$\pm 22,820$	$\pm 9,963$	$\pm 4,539$	$\pm 318$	
<i>Salix bebbiana</i>	14,530	4,800	15,330	1,800	$P = ns$
	$\pm 12,232$	$\pm 9,557$	$\pm 19,508$	$\pm 5,728$	
<i>Amelanchier</i> spp.		80	4,450	9,200	$P = ns$
		$\pm 177$	$\pm 7,242$	$\pm 25,599$	
<i>Lonicera canadensis</i>	290	5,430		8,000	$P = ns$
	$\pm 666$	$\pm 8,881$		$\pm 25,456$	
<i>Prunus pensylvanica</i>	3,960	2,930	950		$P = ns$
	$\pm 4,841$	$\pm 5,560$	$\pm 1,219$		
<i>Populus tremuloides</i>	70	130	1,200	200	$P = ns$
	$\pm 154$	$\pm 177$	$\pm 2,411$	$\pm 636$	
<i>Sorbus americana</i>	110	200	230		$P = ns$
	$\pm 256$	$\pm 473$	$\pm 440$		
<i>Thuja occidentalis</i>	37,960				
	$\pm 61,421$				
<i>Alnus crispa</i>	9,530				
	$\pm 21,984$				
<i>Pinus strobus</i>		4,480			
		$\pm 8,680$			
<i>Cornus rugosa</i>		450			
		$\pm 1,064$			
<i>Viburnum edule</i>			170		
			$\pm 367$		
<i>Acer rubrum</i>			20		
			$\pm 37$		
Total tree seedlings	86,670 <sup>a,b</sup> <sup>4/</sup> $\pm 112,476$	271,230 <sup>a,b</sup> $\pm 342,925$	150,780 <sup>a</sup> $\pm 122,143$	2,250 <sup>b</sup> $\pm 6,339$	$P = 0.050$
Total shrubs	152,040 <sup>a</sup> $\pm 77,866$	64,130 <sup>b</sup> $\pm 44,477$	29,170 <sup>b</sup> $\pm 18,632$	121,100 <sup>a,b</sup> $\pm 225,805$	$P = 0.050$
Total browse	238,710 $\pm 117,244$	335,350 $\pm 361,671$	179,950 $\pm 132,365$	123,350 $\pm 224,227$	$P = ns$

<sup>1/</sup> Numbers of current annual twigs greater than 1 inch in total length and occurring between 6 inches and 10 feet of the ground.

<sup>2/</sup> A "P" value in the last column (significance level) indicates the level of significance of an overall test for differences among the communities in mean browse production by that species.

<sup>3/</sup> For the three species (*Corylus cornuta*, *Betula papyrifera*, and *Acer spicatum*), total tree seedlings, and total shrubs showing an overall difference among the communities at  $P = 0.05$ , values within a row followed by the same letter are not significantly different (at  $P = 0.05$ ).

<sup>4/</sup> Due to rounding errors, columns may not total exactly.

For these same five characters t-tests were run to determine which means were different. Beaked hazel showed only one difference among the communities, with production in the aspen-birch type differing from that in the jack pine-birch. For paper birch the birch type differed from the jack pine. Two differences were apparent for mountain maple where production in the aspen-birch differed from that in both the jack pine-birch and the jack pine types. Total tree seedling twig yield in the jack pine-birch type differed from that in the jack pine type. Total shrub production in the aspen-birch type differed from that in both the birch and jack pine-birch.

Although there were no statistically significant differences in total browse production among the communities, production was highest in the birch type, with 335,350 twigs per acre. The second most productive type was the aspen-birch, with 238,710 twigs per acre. The two coniferous communities produced fewer twigs, averaging 179,950 and 123,350 twigs per acre for the jack pine-birch and jack pine types, respectively.

The species contributing most heavily to total production varied with community type. In the aspen-birch type balsam fir (*Abies balsamea*), beaked hazel, and white-cedar were the most prolific producers. Balsam fir was the dominant producer in both the birch and jack pine-birch types, while most of the production was by beaked hazel in the jack pine community.

## DISCUSSION

Even without statistical analysis it was apparent that there were differences in the vegetation occupying the two burn areas. This was evident during the fieldwork and was supported by the unequal distribution of community types between the burn areas. Thus, an overall comparison of production between the two burn areas involved in part a comparison of community types. The significant difference in total shrub browse production between burn areas was thus confounded by the effects of community type.

Statistically significant differences in production among the community types were limited to three browse species plus total tree seedling browse and total shrub browse. Some other species, such as balsam fir, displayed more than a fivefold difference among the types, but without statistical significance. This apparent anomaly relates to the nature of statistical tests and their dependence upon the variability of the data, which was generally great. Highly variable data for browse production have also been found by other authors, including Blair (1959), Stearns *et al.* (1968), and Dyne *et al.* (1963). As Shafer (1963) remarked, production would have to vary "considerably" between areas before significant differences could be detected.

Lack of a significant difference among the species in total browse production reflected more

than the variability of the data. Peak production by certain species was offset by the relatively poor development of others (table 2). In the birch and jack pine-birch communities, the tree seedlings reached peak production while the yield of shrub browse was low. The converse was true of the aspen-birch and jack pine types with their low tree seedling and high shrub production. Thus, a relatively stable level of production was maintained among the communities. This, along with the high variance estimates, allowed no significant differences in total browse availability even while individual species and species groups did vary significantly.

Comparison of these data with browse production estimates from other studies was difficult due to different means of measurement. This study included all twigs greater than 1 inch in total length--nearly all the twigs in the stand. Halls *et al.* (1970), similarly defining a twig and tallying all twigs within 5 feet of the ground, found more than 300,000 twigs per acre in east Texas pine hardwood forests. Their data compare favorably with my estimates of 123,350 to 335,350 twigs per acre while their zone of availability was considerably less than the 1/2 to 10 feet used in this study. Although their data are hardly comparable, they support my feeling that browse production was, in fact, low in the dense forest communities of the Cherokee-Frost Lake area which were probably past the optimum age for browse production.

The low browse production found in this study has implications for management in that a low carrying capacity may be expected in these community types 30 years postfire, although the forest may again become more productive of browse with age. It is also instructive to note that the predominant species here were beaked hazel and balsam fir. These species are not regarded as high-quality forage for the large mammalian herbivores, although moose are known to use balsam fir in winter. The balsam fir present, however, were generally small seedlings and hence not likely to be browsed. A further implication concerns the relationship between preburn and postburn community types described in the companion article. There the age and composition of the preburn vegetation were found to largely determine the postburn vegetation and, by extension in this study, the level of browse production and its species composition. Therefore, given knowledge of the age and composition of the preburn vegetation and the length of time since fire, we ought to be able to predict the postfire production, albeit with less accuracy as the forest matures.

Future studies of this type should place more emphasis on the browsing habits of the animals. Although moose are known to browse twigs growing 10 feet or more above the ground, Dodds (1960) found that moose prefer to browse plants within easy reach. He found that over 90

percent of the browsing took place within 6 feet of the ground, even in an area of high moose density. Thus, if even the largest herbivore on the study area browses mainly on low-growing forage, the zone of availability may be more practically confined to 6 feet. Another refinement commonly found in the literature is to restrict browse surveys to only those twigs showing more than 1 inch of current annual growth because, as Stearns *et al.* (1968) suggested, twigs shorter than 1 inch are seldom browsed and they contribute little to total production. These two refinements, arbitrarily reducing the zone of availability and tallying only the more preferred, rapidly growing twigs, would allow a greater number of sample plots with concomitant lower variance estimates. As Newbould (1967) advocated, one should direct effort toward minimizing errors in the major components while tolerating larger errors in the minor components.

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# PART III. SMALL MAMMAL POPULATIONS

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## ABSTRACT

Small mammals were snap-trapped for 5,326 trap-station days during summer 1969. Of 142 individuals captured, 103 were either *Peromyscus maniculatus gracilis* or *Clethrionomys gapperi*. Reproductive histories for these two species are discussed. An attempt was made to relate distributions of small mammals to vegetative community types. The sketchy evidence suggests a uniform distribution with no strong linkages to any of the four types. The latter are described in a companion paper.

The distribution, composition, and habitats of small-mammal populations have not been adequately described in the Boundary Waters Canoe Area (BWCA). An intensive study was conducted between 1950 and 1970 around Basswood Lake (T64N, R9W) (Beer *et al.* 1954; Beer, unpublished data; Menzel 1957). Ahlgren (1966) trapped small mammals for four seasons in the area of Bearskin and Grass Lakes (T60N, R9W), and Rom (1940) carried out a minor trapping effort (some 600 trapnights) near Kekekabic Lake (T65N, R6W). Collectively these works comprise the information on small-mammal populations in and near this million-acre area of the Superior National Forest.

Here we report on a study of small mammal populations in the 3,500- and 3,300-acre Cherokee and Frost Lakes (T64N, R4W) wildfires. Collections were made in 1969, 33 years after the fires, in conjunction with a study of plant communities in the BWCA. The latter study is discussed in Part I of this report. Objectives in our study were (1) to prepare a listing of small mammals and (2) to describe correlations between small mammals and plant communities in the wilderness areas of Frost and Cherokee Lakes.

## METHODS

One meandering transect was established in each of 33 stands (fig. 1 and table 10, Part I). Fired standard snap traps (1-1/2" x 3") baited with a mixture of peanut butter and rolled oats were placed at each of 50 stations located at 3-foot intervals along the transect.

Each trapline was operated for 3 consecutive trapnights during the period June 10 to August 31. An exception was stand one, which was trapped for two 3-day and one 2-day periods.

Traplines were checked daily and carcasses removed and preserved in a 10 percent formalin solution. In the laboratory, carcasses were identified as to species, sexed, and measured for tail, ear, and total length. Testes were noted as abdominal or scrotal, and the epididymis as undeveloped or with discernible tubules. The reproductive status of females was characterized by the condition of the mammae (undeveloped or lactating), a perforate or imperforate vaginal orifice, placental scars in the uterus, corpora in the ovaries, and embryos.

## RESULTS AND DISCUSSION

### Species Captured

During a total of 5,326 trap-station days (a trap-pair set for 24 hours = 1 TSD) 142 mammals representing nine species were captured (table 1). One of these, the woodland jumping mouse (*Napeozapus insignis*), is rarely found in Minnesota. The other eight species, some represented by only one or two individuals, are more common to this region.

### Capture Indices

Capture indices (CI), the number of animals captured per 1,000 trap-station days, ranged from 1.3 to 14.1 for species represented by more than two individuals (table 1).

Table 1.--Capture indices<sup>1/</sup> of small mammals in four community types

Community type	Trap-station days	Species							Total
		<i>Peromyscus maniculatus</i>	<i>Clethrionomys gapperi</i>	<i>Eutamias amoenus</i>	<i>Peromyscus leucopus</i>	<i>Thomomys talpae</i>	<i>Microtus pennsylvanicus</i>	Other <sup>2/</sup>	
Aspen-birch	1,534	3/ 2.6 (4)	11.7 (18)	1.3 (2)	1.3 (2)	2.0 (3)	2.0 (3)		20.9 (32)
Birch	1,248	5.6 (7)	13.6 (17)	0.0 (0)	2.4 (3)	2.4 (3)	3.2 (4)		27.2 (34)
Jack pine-birch	1,902	6.3 (12)	18.9 (36)	1.6 (3)	2.1 (4)	5.3 (10)	0.0 (0)		34.2 (65)
Jack pine	642	7.8 (5)	6.2 (4)	3.1 (2)	0.0 (0)	0.0 (0)	0.0 (0)		1.7 (11)
All types	5,326	5.3 (28)	14.1 (75)	1.3 (7)	1.7 (9)	3.0 (16)	1.3 (7)		26.7 (142)

1/ CI = (4) (1,000/1,534) = 2.6.

2/ Includes species represented by one or two individuals: *Microtus pennsylvanicus*, *Thomomys talpae*, *Napeozapus insignis*, *Peromyscus leucopus*.

3/ Number captured is in parentheses.

In order to gain perspective, these data were compared with a long-term study of small-mammal populations in the Basswood Lake area, a region of mature birch-aspen resulting from logging and burning in the early years of this century (Beer, unpublished data). During 3,000 trap-station days in July 1969 the CI for deer mice (*Peromyscus maniculatus gracilis*) was 22. Over a period of 21 years at Basswood, Beer reported that CI's for deer mice varied from 16 to 135 with an average of 49. Ahlgren (1966) trapped deer mice during July for 3 years (1961-1963) in a "relatively homogeneous, mature jack pine stand" in the BWCA and obtained CI's ranging from 50 to 80. It thus appears that the density of deer mice at Frost-Cherokee Lakes, as reflected by a CI of 5, is close to the lowest reported in the BWCA.

The redback vole (*Clethrionomys gapperi*) is normally the second most commonly trapped small mammal, after the deer mouse, in upland habitats of this region. Seventy-five individuals were trapped at Frost and Cherokee Lakes for a CI of 14.1. This is higher than the CI of 7 during the same period at Basswood Lake. Based on 21 years of data from the Basswood area, Beer reported an average CI of 11 and a range from 3 to 37. Ahlgren (1966) obtained CI's ranging from 0 to 150 during his 3-year study. While a CI of 14 for redbacks in the Frost and Cherokee Lakes study is not the lowest reported for the general area, it suggests low population densities in the Frost-Cherokee Lakes area.

The CI's for species other than deer mice and redback voles were too low in our study to make valid comparisons. Other studies in north-eastern Minnesota have reported the same.

### Reproduction

Sixteen of 28 (57 percent) deer mice captured at Frost and Cherokee Lakes were females (table 2). Three of the 16 were pregnant and eight others had placental scars, the latter indicating parturition during 1969. Only five of the 12 males showed signs of being or having been reproductively active. This activity is lower than that of the females and is probably due to the slower maturing of males (Clark 1938)

Table 2.--Status of reproductive systems of the small mammals captured

	Males		Females			
	Number	Number	Number	Number	Number	Number
F.	28	12	16	11 <sup>1/</sup>	4	
M.		26	34	29	20	
F.	1	1				
M.			1	1	1	
F.		1		1		
F.		5	0	2	0	
F.		5		4	0	
M.	16		10		0	
M.	3	1	2		0	

1/ Number of animals in a reproductive status as indicated by mammae, embryos, placental scars, or ovarian corpora.

2/ Positive determinations were not made.

and their higher mortality rate (Beer and MacLeod 1966).

No pregnant females nor reproductively active male deer mice were captured during the August trap period, although three or four females were lactating or had been recently. This suggests that reproduction ceased by the end of July. While sample size is inadequate for firm conclusions, the reproductive histories of mature female deer mice captured during June and July suggest that individuals produced 3.3 litters, assuming the breeding season starts about the first of April (Davis 1956).

Based on three sets of embryos and eight sets of placental scars, the average number of implantations per pregnancy in deer mice was 4.6. Preimplantation loss, based on a comparison of ovarian corpora and implantations, was 8.3 percent. If the 2.1 percent postimplantation loss reported by Beer *et al.* (1957) holds for this population, litter size would be about 4.5. Thus, reproductively active females produced approximately 15 young (3.3 litters x 4.5) between April and the end of the breeding season.

Thirty-four of 77 (44 percent) redback voles captured were females. Twenty of these contained embryos and nine others had borne litters as indicated by placental scars. We captured pregnant females throughout the study; i.e., to the end of August. This supports Beer's observation that the breeding season for redbacks extends from the first of April to the end of September. It so, then fecund females produced 6.9 litters in 1969. Based on 20 sets of embryos and six sets of placental scars and associated ovarian corpora, the potential litter production for redbacks was 5.9. Average implantation was 5.4, so that preimplantation loss was 8.5 percent. There were two dead embryos among the 108 observed, which agrees with the 1.3 percent *in utero* loss reported by Beer *et al.* (1957) for redbacks in the Basswood Lake area. Following these data and estimates, each female redback would have produced about 37 young by the end of September.

### Seasonal Variation in Capture Indices

We expected that CI's would increase during the reproductive season and then decrease. Mean CI for deer mice was 2.9 ( $s_x = 1.1$ ) for June-July and 2.4 ( $s_x = 0.7$ ) during August. This is a significant decline ( $p < .01$ ) and supports our conclusion that reproduction in the deer mouse population had ceased by the end of July.

Mean CI for redback voles, on the other hand, increased significantly ( $p < .01$ ) from 5.0 ( $s_x = 1.0$ ) to 9.3 ( $s_x = 1.6$ ) over the same period. This is supported by our finding that redbacks were reproductively active to the end of the trapping season (late August).

Total CI (all species) also increased significantly ( $p < .01$ ), from 9.9 ( $s_x = 1.7$ ) to 17.3 ( $s_x = 2.9$ ) from June-July to the end of August.

The fact that there is a season effect, negative for the deer mouse and positive for other species, could confound attempts to relate population density to vegetative community types. If, for example, trapping were done in one type early in the season and in another toward the end, then we could not be sure if a significant difference in CI's were due to factors intrinsic in the community types or if it were simply a reflection of the fact that populations in the last type trapped had more time to reproduce or, conversely, more time to suffer mortality.

Therefore, we now advocate that community types be trapped on a random time schedule. We were not able to follow such a schedule and thus may have biased results insofar as we attempt to relate CI's to community types. For example, most of our trapping in June and July was in the aspen-birch type and in late August most was in the birch type. This possible bias is not accounted for in the discussion following.

#### Capture Indices in Relation to Vegetation Types

Grant and Morris (1971) proposed a model of the distribution of animals in relation to habitat structure. Their model integrates two hypotheses: (1) the spatial distribution of animal activity in a patch environment (such as deciduous woodland habitat) is determined more by structural features of the habitat than by population (intrinsic) factors; (2) variations in animal density will modify the relationship between animal and plant distribution; e.g., at low density only the most suitable habitat is occupied. They cite several authors who have found strong associations between animal and vegetation density in woodland habitat.

Thus, for Frost-Cherokee Lakes, we should expect distribution (as reflected in the number of traplines producing animals) to be relatively more even in the more structurally homogeneous vegetation types (birch and jack pine) than in the structurally diverse types (aspen-birch and jack pine-birch). If the effect of population density is considered alone, then we should expect the animals to be aggregated, since, as we have shown, the populations exhibited very low densities.

While our study design was such that Grant and Morris' model might have been subjected to a valid test, the low numbers of animals captured within vegetation types did not allow us to generate indices of animal dispersion, such as Morisita's (cited in Grant and Morris 1971), and thus we can do no more than suggest where linkages of animals and habitat type are more pronounced. Only data for deer mice and redback voles are considered.

Capture indices for deer mice were similar in all four vegetation types, and the density of redbacks was significantly higher in jack pine-birch than in the other three types (table 1).

Evidence for aggregation within a vegetation type might be found by comparing the frequency of capture among traplines within type. For deer mice, traplines in birch and jack pine-birch types were most productive, while redbacks were captured readily in all types, but with greatest success in jack pine-birch and jack pine (table 3).

Twenty of the 35 traplines (57 percent) produced no deer mice, while seven of the 35 (20 percent) yielded two or more animals. Only six of 35 (17 percent) traplines produced no redbacks, while 18 of 35 (51 percent) yielded two or more animals. This is further evidence of the low density of deer mice and relatively high density of redbacks in the study area.

In conclusion, densities of deer mice and redback voles were extremely low compared with results from other studies in the BWCA. Because of limited numbers of animals captured within plant community types, we were not able to test the basic model of animal distribution (Grant and Morris 1971), which for northeastern Minnesota most likely would show aggregations of the animals in the most suitable habitats. The sketchy evidence suggests a uniform small-mammal distribution with no strong linkages to any of the four vegetation types in the Frost-Cherokee area. We suspect that this may be due to missing elements of food and/or shelter, although we cannot be certain because we know so little about the habitat requirements of the deer mouse and the redback vole in virgin

Table 3.--Percent of traplines by community types that produced specimens of a given species

Community type	:Number: :trap- :lines	Species						
		<i>Peromyscus</i>	<i>Peromyscus</i>	<i>Peromyscus</i>	<i>Peromyscus</i>	<i>Peromyscus</i>	<i>Peromyscus</i>	Other
		<i>leucurus</i>	<i>leucurus</i>	<i>leucurus</i>	<i>leucurus</i>	<i>leucurus</i>	<i>leucurus</i>	
Aspen-birch	11	36 (4) <sup>1/</sup>	64 (7)	18 (2)	18 (2)	27 (3)	27 (3)	
Birch	8	50 (4)	88 (7)	0 (0)	38 (3)	12 (1)	38 (3)	
Jack pine-birch	12	50 (6)	92 (11)	25 (3)	33 (4)	33 (4)	0 (0)	
Jack pine	4	25 (1)	100 (4)	50 (2)	0 (0)	0 (0)	0 (0)	
All types	35	43 (15)	83 (29)	20 (7)	26 (9)	23 (8)	17 (6)	

<sup>1/</sup> The number of traplines that produced at least one mouse; 4 ÷ 11 = 36 percent.

plant communities. It is evident that plant communities in the Frost-Cherokee area are different in some respects than younger or older virgin communities. Ohmann in Part I of this report, for example, notes that the blueberries (*Vaccinium*) and wintergreen (*Gaultheria*) are far from being reestablished at Frost-Cherokee, and that this is probably due to the severity of the drought-year (1936) fire which may have consumed the seed sources of blueberries and wintergreen. Other possible components of small-mammal habitat may likewise be missing or in short supply because of the intensity of the fire.

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# TABLES AND CONVERSIONS FOR MICROCLIMATOLOGY

JAMES M. BROWN



**equations or radiant energy exchange;**  
**unit conversion factor;**  
**psychometric and precipitation data;**  
**solar radiation diagrams;**

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# TABLES AND CONVERSIONS FOR MICROCLIMATOLOGY

James M. Brown

## INTRODUCTION

This collection of tables and conversion factors will aid climatologists, foresters, biologists, and others who are concerned with measuring and evaluating microclimate. Much of the material here has not been presented before, or has not been given with sufficient detail to serve as a useful reference. Other material is easily available but has been incorporated here to enhance the usefulness of this collection as a single source reference.

Unless otherwise noted, all constants used in the calculation of the tables and figures are from List (1968). The topic of solar beam irradiation on sloping surfaces has been omitted from this collection and the user is referred to the tables of Fons *et al.* (1960) and Frank and Lee (1966). The items within the lists of conversion factors are arranged alphabetically.

The author assumes full responsibility for any errors or inaccuracies and would appreciate having them called to his attention.

## RADIANT ENERGY

### Rate--Stefan-Boltzmann Law

Any substance warmer than absolute zero ( $-273.2^{\circ}\text{C}$ ) radiates energy at a rate directly proportional to the fourth power of its absolute temperature. For a perfect radiator, or "black body," the rate of radiant energy emission may be found by the Stefan-Boltzmann law:

$$W = \sigma T^4$$

where  $W$  is the rate of radiant energy emission ( $\text{cal cm}^{-2} \text{ min}^{-1}$ );  $\sigma$  is the Stefan-Boltzmann constant ( $8.132 \times 10^{-11} \text{ cal cm}^{-2} \text{ min}^{-1} \text{ }^{\circ}\text{K}^{-4}$ ); and  $T$  is the absolute temperature ( $^{\circ}\text{K}$ ) of the radiating surface.

Table 1 is the solution of the Stefan-Boltzmann equation for various temperatures in

degrees Centigrade, and tenths, and table 2 presents  $W$  values for Fahrenheit temperatures.

For less-than-perfect radiators, or "gray bodies," the rate of radiant energy emission may be found by multiplying the maximum or "black body" values by the appropriate emissivity factor.

### Spectral Distribution--Planck's Law

The intensity of energy emitted by a black body at various wavelengths is described by Planck's law:

$$W\lambda = c_1 \lambda^{-5} \left( \exp \frac{c_2}{\lambda T} - 1 \right)^{-1}$$

where  $W\lambda$  is the intensity of energy emitted at wavelength  $\lambda$ ,  $c_1$  and  $c_2$  are constants, and  $T$  is the absolute temperature ( $^{\circ}\text{K}$ ) of the black body source.

Tables 3 and 4 are solutions of Planck's law for a range of typical terrestrial temperatures, in degrees Centigrade. Table 3 gives values for  $W\lambda$  in  $\text{ergs cm}^{-2} \text{ sec}^{-1} \text{ cm}$  of wavelength $^{-1}$ , where constant  $c_1 = 3.740 \times 10^{-1} \text{ erg cm}^{-2} \text{ sec}^{-1}$  and  $c_2 = 1.4835 \text{ cm }^{\circ}\text{K}$ . In table 4 these values have been converted to give  $W\lambda$  in  $\text{cal cm}^{-2} \text{ min}^{-1} \text{ micron of wavelength}^{-1}$ .

### Peak Intensity--Wien's Displacement Law

The wavelength of maximum emission may be found by Wien's displacement law:

$$\lambda_{\max} = 2897 \text{ micron }^{\circ}\text{K } T^{-1}$$

where  $\lambda_{\max}$  is the wavelength of maximum emission (microns), and  $T$  is the absolute temperature ( $^{\circ}\text{K}$ ) of the radiating body.

Table 5 presents  $\lambda_{\max}$  values for various temperatures. This table also includes the total energy radiated at these temperatures, the frequency of maximum emission (reciprocal of wavelength), and the intensity of the radiant energy flux at maximum emission.

Table 1.--Solution of the Stefan-Boltzmann law,  $W = \sigma T^4$ , for temperatures in degrees Centigrade.  $W$  is the rate of energy emission in cal  $\text{cm}^{-2} \text{min}^{-1}$  for a black body

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
-40	0.2397	0.2393	0.2389	0.2384	0.2380	0.2376	0.2372	0.2368	0.2364	0.2360
-39	.2438	.2434	.2430	.2426	.2422	.2417	.2413	.2409	.2405	.2401
-38	.2480	.2476	.2472	.2467	.2463	.2459	.2455	.2451	.2446	.2442
-37	.2523	.2518	.2514	.2510	.2506	.2501	.2497	.2493	.2489	.2484
-36	.2566	.2561	.2557	.2553	.2548	.2544	.2540	.2535	.2531	.2527
-35	.2609	.2605	.2600	.2596	.2592	.2587	.2583	.2579	.2574	.2570
-34	.2653	.2649	.2644	.2640	.2636	.2631	.2627	.2622	.2618	.2614
-33	.2698	.2694	.2689	.2685	.2680	.2676	.2671	.2667	.2662	.2658
-32	.2743	.2739	.2734	.2730	.2725	.2721	.2716	.2712	.2707	.2703
-31	.2789	.2784	.2780	.2775	.2771	.2766	.2762	.2757	.2752	.2748
-30	.2835	.2831	.2826	.2821	.2817	.2812	.2808	.2803	.2798	.2794
-29	.2882	.2878	.2873	.2868	.2864	.2859	.2854	.2849	.2845	.2840
-28	.2930	.2925	.2920	.2916	.2911	.2906	.2901	.2897	.2892	.2887
-27	.2978	.2973	.2968	.2964	.2959	.2954	.2949	.2944	.2940	.2935
-26	.3027	.3022	.3017	.3012	.3007	.3002	.2998	.2993	.2988	.2983
-25	.3076	.3071	.3066	.3061	.3056	.3051	.3046	.3042	.3037	.3032
-24	.3126	.3121	.3116	.3111	.3106	.3101	.3096	.3091	.3086	.3081
-23	.3177	.3171	.3166	.3161	.3156	.3151	.3146	.3141	.3136	.3131
-22	.3228	.3223	.3217	.3212	.3207	.3202	.3197	.3192	.3187	.3182
-21	.3279	.3274	.3269	.3264	.3259	.3253	.3248	.3243	.3238	.3233
-20	.3332	.3327	.3321	.3316	.3311	.3306	.3300	.3295	.3290	.3285
-19	.3385	.3379	.3374	.3369	.3364	.3358	.3353	.3348	.3342	.3337
-18	.3438	.3433	.3428	.3422	.3417	.3412	.3406	.3401	.3395	.3390
-17	.3493	.3487	.3482	.3476	.3471	.3465	.3460	.3455	.3449	.3444
-16	.3548	.3542	.3537	.3531	.3526	.3520	.3515	.3509	.3504	.3498
-15	.3603	.3598	.3592	.3586	.3581	.3575	.3570	.3564	.3559	.3553
-14	.3659	.3654	.3648	.3642	.3637	.3631	.3625	.3620	.3614	.3609
-13	.3716	.3710	.3705	.3699	.3693	.3688	.3682	.3676	.3671	.3665
-12	.3774	.3768	.3762	.3756	.3751	.3745	.3739	.3733	.3728	.3722
-11	.3832	.3826	.3820	.3814	.3808	.3803	.3797	.3791	.3785	.3779
-10	.3891	.3885	.3879	.3873	.3867	.3861	.3855	.3849	.3844	.3838
-9	.3950	.3944	.3938	.3932	.3926	.3920	.3914	.3908	.3902	.3897
-8	.4010	.4004	.3998	.3992	.3986	.3980	.3974	.3968	.3962	.3956
-7	.4071	.4065	.4059	.4053	.4047	.4041	.4035	.4029	.4022	.4016
-6	.4133	.4127	.4120	.4114	.4108	.4102	.4096	.4090	.4083	.4077
-5	.4195	.4189	.4183	.4176	.4170	.4164	.4158	.4151	.4145	.4139
-4	.4258	.4252	.4245	.4239	.4233	.4226	.4220	.4214	.4208	.4201
-3	.4322	.4315	.4309	.4303	.4296	.4290	.4283	.4277	.4271	.4264
-2	.4386	.4380	.4373	.4367	.4360	.4354	.4347	.4341	.4334	.4328
-1	.4451	.4445	.4438	.4432	.4425	.4419	.4412	.4406	.4399	.4393
-0	.4517	.4510	.4504	.4497	.4491	.4484	.4477	.4471	.4464	.4458
+0	.4517	.4524	.4530	.4537	.4544	.4550	.4557	.4563	.4570	.4577
1	.4584	.4590	.4597	.4604	.4610	.4617	.4624	.4631	.4637	.4644
2	.4651	.4658	.4664	.4671	.4678	.4685	.4692	.4698	.4705	.4712
3	.4719	.4726	.4733	.4739	.4746	.4753	.4760	.4767	.4774	.4781
4	.4788	.4795	.4801	.4808	.4815	.4822	.4829	.4836	.4843	.4850
5	.4857	.4864	.4871	.4878	.4885	.4892	.4899	.4906	.4913	.4920
6	.4927	.4934	.4942	.4949	.4956	.4963	.4970	.4977	.4984	.4991
7	.4998	.5006	.5013	.5020	.5027	.5034	.5041	.5049	.5056	.5063
8	.5070	.5077	.5085	.5092	.5099	.5106	.5114	.5121	.5128	.5135
9	.5143	.5150	.5157	.5165	.5172	.5179	.5187	.5194	.5201	.5209
10	.5216	.5223	.5231	.5238	.5246	.5253	.5260	.5268	.5275	.5283
11	.5290	.5298	.5305	.5313	.5320	.5328	.5335	.5343	.5350	.5358
12	.5365	.5373	.5380	.5388	.5395	.5403	.5410	.5418	.5426	.5433
13	.5441	.5448	.5456	.5464	.5471	.5479	.5487	.5494	.5502	.5510

Continued on next page

Table 1 continued

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
14	0.5517	0.5525	0.5533	0.5540	0.5548	0.5556	0.5564	0.5571	0.5579	0.5587
15	.5595	.5602	.5610	.5618	.5626	.5634	.5641	.5649	.5657	.5665
16	.5673	.5681	.5688	.5696	.5704	.5712	.5720	.5728	.5736	.5744
17	.5752	.5760	.5767	.5775	.5783	.5791	.5799	.5807	.5815	.5823
18	.5831	.5839	.5847	.5855	.5863	.5872	.5880	.5888	.5896	.5904
19	.5912	.5920	.5928	.5936	.5944	.5953	.5961	.5969	.5977	.5985
20	.5993	.6002	.6010	.6018	.6026	.6034	.6043	.6051	.6059	.6067
21	.6076	.6084	.6092	.6100	.6109	.6117	.6125	.6134	.6142	.6150
22	.6159	.6167	.6175	.6184	.6192	.6201	.6209	.6217	.6226	.6234
23	.6243	.6251	.6259	.6268	.6276	.6285	.6293	.6302	.6310	.6319
24	.6327	.6336	.6344	.6353	.6362	.6370	.6379	.6387	.6396	.6404
25	.6413	.6422	.6430	.6439	.6448	.6456	.6465	.6473	.6482	.6491
26	.6500	.6508	.6517	.6526	.6534	.6543	.6552	.6561	.6569	.6578
27	.6587	.6596	.6605	.6613	.6622	.6631	.6640	.6649	.6657	.6666
28	.6675	.6684	.6693	.6702	.6711	.6720	.6729	.6737	.6746	.6755
29	.6764	.6773	.6782	.6791	.6800	.6809	.6818	.6827	.6836	.6845
30	.6854	.6863	.6872	.6882	.6891	.6900	.6909	.6918	.6927	.6936
31	.6945	.6954	.6964	.6973	.6982	.6991	.7000	.7010	.7019	.7028
32	.7037	.7046	.7056	.7065	.7074	.7083	.7093	.7102	.7111	.7121
33	.7130	.7139	.7149	.7158	.7167	.7177	.7186	.7195	.7205	.7214
34	.7224	.7233	.7242	.7252	.7261	.7271	.7280	.7290	.7299	.7309
35	.7318	.7328	.7337	.7347	.7356	.7366	.7375	.7385	.7394	.7404
36	.7414	.7423	.7433	.7442	.7452	.7462	.7471	.7481	.7491	.7500
37	.7510	.7520	.7529	.7539	.7549	.7559	.7568	.7578	.7588	.7598
38	.7607	.7617	.7627	.7637	.7647	.7656	.7666	.7676	.7686	.7696
39	.7706	.7716	.7726	.7735	.7745	.7755	.7765	.7775	.7785	.7795
40	.7805	.7815	.7825	.7835	.7845	.7855	.7865	.7875	.7885	.7895
41	.7905	.7915	.7925	.7936	.7946	.7956	.7966	.7976	.7986	.7996
42	.8006	.8017	.8027	.8037	.8047	.8057	.8068	.8078	.8088	.8098
43	.8109	.8119	.8129	.8139	.8150	.8160	.8170	.8181	.8191	.8201
44	.8212	.8222	.8232	.8243	.8253	.8264	.8274	.8284	.8295	.8305
45	.8316	.8326	.8337	.8347	.8358	.8368	.8379	.8389	.8400	.8410
46	.8421	.8431	.8442	.8453	.8463	.8474	.8484	.8495	.8506	.8516
47	.8527	.8538	.8548	.8559	.8570	.8580	.8591	.8602	.8613	.8623
48	.8634	.8645	.8656	.8666	.8677	.8688	.8699	.8710	.8721	.8731
49	.8742	.8753	.8764	.8775	.8786	.8797	.8808	.8818	.8829	.8840
50	.8851	.8862	.8873	.8884	.8895	.8906	.8917	.8928	.8939	.8950
51	.8961	.8973	.8984	.8995	.9006	.9017	.9028	.9039	.9050	.9061
52	.9073	.9084	.9095	.9106	.9117	.9129	.9140	.9151	.9162	.9173
53	.9185	.9196	.9207	.9219	.9230	.9241	.9253	.9264	.9275	.9287
54	.9298	.9309	.9321	.9332	.9344	.9355	.9366	.9378	.9389	.9401
55	.9412	.9424	.9435	.9447	.9458	.9470	.9481	.9493	.9504	.9516
56	.9528	.9539	.9551	.9562	.9574	.9586	.9597	.9609	.9621	.9632
57	.9644	.9656	.9667	.9679	.9691	.9702	.9714	.9726	.9738	.9750
58	.9761	.9773	.9785	.9797	.9809	.9820	.9832	.9844	.9856	.9868
59	.9880	.9892	.9904	.9916	.9928	.9939	.9951	.9963	.9975	.9987
60	.9999	1.0011	1.0023	1.0035	1.0048	1.0060	1.0072	1.0084	1.0096	1.0108
61	1.0120	1.0132	1.0144	1.0156	1.0169	1.0181	1.0193	1.0205	1.0217	1.0230
62	1.0242	1.0254	1.0266	1.0279	1.0291	1.0303	1.0315	1.0328	1.0340	1.0352
63	1.0365	1.0377	1.0389	1.0402	1.0414	1.0426	1.0439	1.0451	1.0464	1.0476
64	1.0489	1.0501	1.0514	1.0526	1.0538	1.0551	1.0563	1.0576	1.0589	1.0601
65	1.0614	1.0626	1.0639	1.0651	1.0664	1.0677	1.0689	1.0702	1.0714	1.0727
66	1.0740	1.0752	1.0765	1.0778	1.0791	1.0803	1.0816	1.0829	1.0842	1.0854
67	1.0867	1.0880	1.0893	1.0905	1.0918	1.0931	1.0944	1.0957	1.0970	1.0983
68	1.0995	1.1008	1.1021	1.1034	1.1047	1.1060	1.1073	1.1086	1.1099	1.1112

Continued on next page

Table 1 continued

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
69	1.1125	1.1138	1.1151	1.1164	1.1177	1.1190	1.1203	1.1216	1.1230	1.1243
70	1.1256	1.1269	1.1282	1.1295	1.1308	1.1322	1.1335	1.1348	1.1361	1.1374
71	1.1388	1.1401	1.1414	1.1427	1.1441	1.1454	1.1467	1.1481	1.1494	1.1507
72	1.1521	1.1534	1.1547	1.1561	1.1574	1.1587	1.1601	1.1614	1.1628	1.1641
73	1.1655	1.1668	1.1682	1.1695	1.1709	1.1722	1.1736	1.1749	1.1763	1.1776
74	1.1790	1.1804	1.1817	1.1831	1.1844	1.1858	1.1872	1.1885	1.1899	1.1913
75	1.1927	1.1940	1.1954	1.1968	1.1981	1.1995	1.2009	1.2023	1.2037	1.2050
76	1.2064	1.2078	1.2092	1.2106	1.2120	1.2133	1.2147	1.2161	1.2175	1.2189
77	1.2203	1.2217	1.2231	1.2245	1.2259	1.2273	1.2287	1.2301	1.2315	1.2329
78	1.2343	1.2357	1.2371	1.2385	1.2400	1.2414	1.2428	1.2442	1.2456	1.2470
79	1.2484	1.2499	1.2513	1.2527	1.2541	1.2555	1.2570	1.2584	1.2598	1.2613
80	1.2627	1.2641	1.2656	1.2670	1.2684	1.2699	1.2713	1.2727	1.2742	1.2756
81	1.2771	1.2785	1.2799	1.2814	1.2828	1.2843	1.2857	1.2872	1.2886	1.2901
82	1.2915	1.2930	1.2945	1.2959	1.2974	1.2988	1.3003	1.3018	1.3032	1.3047
83	1.3062	1.3076	1.3091	1.3106	1.3120	1.3135	1.3150	1.3165	1.3179	1.3194
84	1.3201	1.3224	1.3239	1.3253	1.3268	1.3283	1.3298	1.3313	1.3328	1.3343
85	1.3358	1.3373	1.3388	1.3402	1.3417	1.3432	1.3447	1.3462	1.3477	1.3492
86	1.3508	1.3523	1.3538	1.3553	1.3568	1.3583	1.3598	1.3613	1.3628	1.3643
87	1.3659	1.3674	1.3689	1.3704	1.3719	1.3735	1.3750	1.3765	1.3780	1.3796
88	1.3811	1.3826	1.3842	1.3857	1.3872	1.3888	1.3903	1.3918	1.3934	1.3949
89	1.3965	1.3980	1.3996	1.4011	1.4027	1.4042	1.4058	1.4073	1.4089	1.4104
90	1.4120	1.4135	1.4151	1.4166	1.4182	1.4198	1.4213	1.4229	1.4244	1.4260
91	1.4276	1.4292	1.4307	1.4323	1.4339	1.4354	1.4370	1.4386	1.4402	1.4418
92	1.4433	1.4449	1.4465	1.4481	1.4497	1.4513	1.4529	1.4544	1.4560	1.4576
93	1.4592	1.4608	1.4624	1.4640	1.4656	1.4672	1.4688	1.4704	1.4720	1.4736
94	1.4752	1.4768	1.4785	1.4801	1.4817	1.4833	1.4849	1.4865	1.4881	1.4898
95	1.4914	1.4930	1.4946	1.4963	1.4979	1.4995	1.5011	1.5028	1.5044	1.5060
96	1.5077	1.5093	1.5109	1.5126	1.5142	1.5158	1.5175	1.5191	1.5208	1.5224
97	1.5241	1.5257	1.5274	1.5290	1.5307	1.5323	1.5340	1.5356	1.5373	1.5390
98	1.5406	1.5423	1.5439	1.5456	1.5473	1.5489	1.5506	1.5523	1.5539	1.5556
99	1.5573	1.5590	1.5606	1.5623	1.5640	1.5657	1.5674	1.5690	1.5707	1.5724
100	1.5741	1.5758	1.5775	1.5792	1.5809	1.5826	1.5843	1.5860	1.5876	1.5893

Table 2.--Solution of the Stefan-Boltzmann law,  $W = \sigma T^4$ , for temperatures in degrees Fahrenheit.  $W$  is the rate of energy emission in  $\text{cal cm}^{-2} \text{min}^{-1}$  for a black body

°F	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
-30	0.2635	0.2611	0.2586	0.2562	0.2538	0.2515	0.2491	0.2468	0.2444	0.2421
-20	.2889	.2863	.2837	.2811	.2785	.2760	.2735	.2709	.2685	.2660
-10	.3161	.3133	.3105	.3077	.3050	.3023	.2996	.2969	.2942	.2915
-0	.3451	.3421	.3392	.3362	.3333	.3304	.3275	.3246	.3217	.3189
+0	.3451	.3481	.3512	.3542	.3573	.3604	.3635	.3666	.3698	.3730
10	.3762	.3794	.3826	.3858	.3891	.3924	.3957	.3991	.4024	.4058
20	.4092	.4126	.4161	.4195	.4230	.4265	.4301	.4336	.4372	.4408
30	.4444	.4480	.4517	.4554	.4591	.4628	.4666	.4703	.4741	.4780
40	.4818	.4857	.4896	.4935	.4974	.5014	.5054	.5094	.5134	.5175
50	.5215	.5256	.5298	.5339	.5381	.5423	.5465	.5508	.5550	.5593
60	.5637	.5680	.5724	.5768	.5812	.5857	.5901	.5946	.5992	.6037
70	.6083	.6129	.6175	.6222	.6269	.6316	.6363	.6411	.6459	.6507
80	.6555	.6604	.6653	.6702	.6752	.6802	.6852	.6902	.6953	.7004
90	.7055	.7106	.7158	.7210	.7262	.7315	.7368	.7421	.7474	.7528
100	.7582	.7636	.7691	.7746	.7801	.7857	.7912	.7968	.8025	.8081
110	.8138	.8196	.8253	.8311	.8369	.8428	.8487	.8546	.8605	.8665
120	.8725	.8785	.8846	.8907	.8968	.9030	.9092	.9154	.9216	.9279
130	.9342	.9406	.9470	.9534	.9598	.9663	.9728	.9794	.9860	.9926
140	.9992	1.0059	1.0126	1.0194	1.0261	1.0330	1.0398	1.0467	1.0536	1.0605
150	1.0675	1.0746	1.0816	1.0887	1.0958	1.1030	1.1102	1.1174	1.1247	1.1320
160	1.1393	1.1467	1.1541	1.1615	1.1690	1.1765	1.1840	1.1916	1.1992	1.2069
170	1.2146	1.2223	1.2301	1.2379	1.2457	1.2536	1.2615	1.2695	1.2775	1.2855
180	1.2936	1.3017	1.3098	1.3180	1.3262	1.3345	1.3428	1.3511	1.3595	1.3679
190	1.3764	1.3849	1.3934	1.4020	1.4106	1.4192	1.4279	1.4366	1.4454	1.4542

Table 3.--Solution of Planck's law,  $\lambda\lambda = c_1\lambda^{-5} (\exp \frac{c_2}{\lambda T} - 1)^{-1}$ , for temperatures in degrees C and wavelengths in  $\mu\text{m}$ .  $\lambda\lambda$  is the intensity of black body energy emission in  $\text{ergs cm}^{-2} \text{sec}^{-1} \mu\text{m}^{-1}$

Wave-length (cm)	Wave number $\text{cm}^{-1}$	Temperature ( $^{\circ}\text{C}$ )																	
		-10	0	10	20	30	40	50	60	70	80	90	100	100	100	100	100	100	100
0.0002	5,000.00	0.0006	0.0019	0.0048	0.0118	0.0273	0.0597	0.1243	0.2477	0.4742	0.8750	1.5610	2.6997	4.6997	8.7500	15.610	26.997	46.997	87.500
0.0004	2,500.00	0.0274	0.0460	0.0743	0.1162	0.1765	0.2610	0.3766	0.5317	0.7357	0.9994	1.3348	1.7555	2.3348	3.1348	4.2348	5.6348	7.3348	9.3348
0.0006	1,666.67	0.3975	0.6667	1.0000	1.4000	1.8667	2.4000	3.0000	3.6667	4.4000	5.2000	6.0667	7.0000	8.0000	9.1333	10.4000	11.8000	13.3333	15.0000
0.0008	1,250.00	0.9000	1.2822	1.6304	2.0398	2.5146	3.0591	3.6770	4.3715	5.1455	6.0016	6.9418	7.9679	9.0818	10.2822	11.5618	12.9298	14.3971	15.9638
0.0010	1,000.00	1.3326	1.6398	1.9888	2.3809	2.8171	3.2983	3.8250	4.3973	5.0154	5.6790	6.3880	7.1418	7.9418	8.7918	9.6918	10.6418	11.6418	12.6918
0.0012	833.33	1.3788	1.6407	1.9290	2.2438	2.5848	2.9518	3.3443	3.7618	4.2039	4.6698	5.1590	5.6709	6.2039	6.7590	7.3361	7.9361	8.5590	9.1961
0.0014	714.29	1.2596	1.4641	1.6846	1.9205	2.1716	2.4373	2.7172	3.0107	3.3173	3.6366	3.9680	4.3110	4.6640	5.0270	5.4000	5.7830	6.1760	6.5790
0.0016	625.00	1.0819	1.2362	1.3999	1.5729	1.7546	1.9446	2.1426	2.3482	2.5610	2.7807	3.0070	3.2395	3.4770	3.7195	3.9670	4.2195	4.4770	4.7395
0.0018	555.56	0.9014	1.0166	1.1376	1.2641	1.3958	1.5322	1.6734	1.8190	1.9686	2.1221	2.2793	2.4400	2.6040	2.7710	2.9410	3.1140	3.2900	3.4690
0.0020	500.00	0.7405	0.8268	0.9167	1.0099	1.1062	1.2055	1.3075	1.4121	1.5192	1.6286	1.7401	1.8536	1.9691	2.0866	2.2061	2.3276	2.4511	2.5766
0.0030	333.33	0.2771	0.3007	0.3247	0.3492	0.3741	0.3993	0.4249	0.4507	0.4768	0.5032	0.5298	0.5566	0.5836	0.6106	0.6376	0.6646	0.6916	0.7186
0.0040	250.00	0.1179	0.1264	0.1349	0.1435	0.1521	0.1609	0.1697	0.1785	0.1875	0.1964	0.2054	0.2145	0.2236	0.2327	0.2418	0.2509	0.2600	0.2691
0.0050	200.00	0.0572	0.0601	0.0631	0.0661	0.0691	0.0721	0.0751	0.0781	0.0811	0.0841	0.0871	0.0901	0.0931	0.0961	0.0991	0.1021	0.1051	0.1081
0.0060	166.67	0.0383	0.0396	0.0409	0.0422	0.0435	0.0448	0.0461	0.0474	0.0487	0.0500	0.0513	0.0526	0.0539	0.0552	0.0565	0.0578	0.0591	0.0604
0.0070	142.86	0.0197	0.0199	0.0201	0.0203	0.0205	0.0207	0.0209	0.0211	0.0213	0.0215	0.0217	0.0219	0.0221	0.0223	0.0225	0.0227	0.0229	0.0231
0.0080	125.00	0.0115	0.0117	0.0119	0.0121	0.0123	0.0125	0.0127	0.0129	0.0131	0.0133	0.0135	0.0137	0.0139	0.0141	0.0143	0.0145	0.0147	0.0149
0.0090	111.11	0.0076	0.0077	0.0078	0.0079	0.0080	0.0081	0.0082	0.0083	0.0084	0.0085	0.0086	0.0087	0.0088	0.0089	0.0090	0.0091	0.0092	0.0093
0.0100	100.00	0.0045	0.0046	0.0047	0.0048	0.0049	0.0050	0.0051	0.0052	0.0053	0.0054	0.0055	0.0056	0.0057	0.0058	0.0059	0.0060	0.0061	0.0062
0.0000	10.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Wave-length (microns)	Wave number $\text{cm}^{-1}$	Temperature ( $^{\circ}\text{C}$ )																	
		-10	0	10	20	30	40	50	60	70	80	90	100	100	100	100	100	100	100
2	0.5000	0.0010	0.0027	0.0069	0.0170	0.0391	0.0855	0.1782	0.3551	0.6797	1.2543	2.2377	3.8701	6.7901	12.543	22.377	38.701	67.901	125.43
4	0.2500	0.0033	0.0093	0.0250	0.0666	0.1530	0.3741	0.8599	1.9622	4.5346	10.4326	23.7135	54.1262	125.43	281.4326	637.135	1432.62	3214.326	7214.326
6	0.1667	0.0058	0.0167	0.0435	0.1118	0.2792	0.6667	1.6667	4.1118	10.4326	23.7135	54.1262	125.43	281.4326	637.135	1432.62	3214.326	7214.326	16000.000
8	0.1250	0.0083	0.0250	0.0635	0.1667	0.4350	1.1118	2.8148	7.1429	18.1818	46.2963	117.6471	296.2963	740.7407	1875.1875	4761.4761	11960.1196	29950.2995	74074.0741
10	0.1000	0.0100	0.0315	0.0800	0.2000	0.5000	1.2500	3.1250	7.8125	19.5312	49.0625	122.6562	306.6406	766.6016	1916.5833	4776.6016	11916.5833	29916.5833	74016.5833
12	0.0833	0.0125	0.0391	0.1000	0.2500	0.6250	1.5625	3.9062	9.7656	24.4141	61.6583	154.1458	386.5896	966.4241	2416.5896	6116.5896	15416.5896	38616.5896	96616.5896
14	0.0714	0.0143	0.0448	0.1176	0.2963	0.7407	1.8519	4.6296	11.6905	29.2308	72.6562	181.6583	451.6583	1129.1658	2816.5896	7016.5896	17516.5896	43916.5896	10916.5896
16	0.0625	0.0167	0.0519	0.1333	0.3333	0.8333	2.0833	5.2083	13.1667	32.9167	82.6667	206.6667	516.6667	1281.6667	3216.6667	8016.6667	20016.6667	50016.6667	125016.6667
18	0.0556	0.0190	0.0593	0.1500	0.3750	0.9375	2.3438	5.9375	14.8438	37.3438	93.7500	234.3750	584.3750	1460.9375	3660.9375	9160.9375	22900.9375	57260.9375	143160.9375
20	0.0500	0.0200	0.0625	0.1600	0.4000	1.0000	2.5000	6.2500	15.6250	39.0625	97.6562	244.1406	606.1406	1516.1406	3791.4062	9476.4062	23691.4062	59226.4062	148061.4062
30	0.0333	0.0333	0.1000	0.2500	0.6250	1.5625	3.9062	9.7656	24.4141	61.6583	154.1458	386.5896	966.4241	2416.5896	6116.5896	15416.5896	38616.5896	96616.5896	241616.5896
40	0.0250	0.0250	0.0769	0.1923	0.4808	1.2020	3.0050	7.5125	18.7812	46.9531	117.1625	291.6512	726.6512	1816.5125	4541.5125	11351.5125	28376.5125	70916.5125	177261.5125
50	0.0200	0.0200	0.0615	0.1538	0.3846	0.9615	2.4038	6.0154	15.0385	37.3438	93.7500	234.3750	584.3750	1460.9375	3660.9375	9160.9375	22900.9375	57260.9375	143160.9375
60	0.0167	0.0167	0.0500	0.1250	0.3125	0.7812	1.9531	4.9062	12.2656	30.6172	76.6583	191.6583	4776.6016	11916.5833	29916.5833	74016.5833	185016.5833	46266.5833	115661.5833
70	0.0143	0.0143	0.0435	0.1091	0.2708	0.6750	1.6905	4.2406	10.6172	26.6583	66.6016	166.5896	416.5896	1041.6583	2601.6583	6501.6583	16266.5896	40616.5896	101661.5896
80	0.0125	0.0125	0.0377	0.0938	0.2344	0.5896	1.4738	3.6905	9.2308	23.0833	57.6562	144.1406	356.1406	881.4062	2201.4062	5501.4062	13766.4062	34266.4062	85661.4062
90	0.0111	0.0111	0.0333	0.0833	0.2083	0.5208	1.3021	3.2656	8.1667	20.3438	50.7656	126.6583	311.6583	771.6583	1926.6583	4816.6583	12066.6583	30166.6583	75166.6583
100	0.0100	0.0100	0.0300	0.0769	0.1923	0.4808	1.2020	3.0050	7.5125	18.7812	46.9531	117.1625	291.6512	726.6512	1816.5125	4541.5125	11351.5125	28376.5125	70916.5125
1,000	0.0010	0.0010	0.0033	0.0083	0.0208	0.0519	0.1281	0.3163	0.7812	1.9531	4.9062	12.2656	30.6172	76.6583	191.6583	4776.6016	11916.5833	29916.5833	74016.5833

Table 4.--Solution of Planck's law,  $\lambda\lambda = c_1\lambda^{-5} (\exp \frac{c_2}{\lambda T} - 1)^{-1}$ , for temperatures in degrees C and wavelengths in microns.  $\lambda\lambda$  is the intensity of black body emission in  $\text{cal cm}^{-2} \text{min}^{-1} \mu\text{m}^{-1}$

Table 5.--Total radiant energy ( $W$ ), wave number ( $\tilde{\nu}$ ) and wave-length ( $\lambda$ ) of maximum emission, and intensity of maximum emission ( $W_{\max}$ ) from a black body source

Temperature: (°C)	$W$	$\tilde{\nu}_{\max}$	$\lambda_{\max}$	$W_{\max}$	$W_{\max}$
	$\frac{\text{Cal}}{\text{cm}^2 \text{ min}} \times 10^{-1}$	$\frac{\text{Wave number}}{\text{cm}^{-1}}$	$\mu$	$\frac{\text{Erg}}{\text{sec}^{-1} \text{ cm}^2} \times 10^7$	$\frac{\text{Cal}}{\text{min}^{-1} \text{ cm}^2} \times 10^{-1}$
-40	0.2397	804.3	12.4335	7.5608	0.1084
-39	.2438	807.7	12.3803	7.7245	.1107
-38	.2480	811.2	12.3277	7.8909	.1131
-37	.2523	814.6	12.2754	8.0602	.1155
-36	.2566	818.1	12.2236	8.2325	.1180
-35	.2609	821.5	12.1723	8.4076	.1205
-34	.2653	825.0	12.1213	8.5857	.1231
-33	.2698	828.4	12.0708	8.7669	.1257
-32	.2743	831.9	12.0207	8.9510	.1283
-31	.2789	835.3	11.9711	9.1383	.1310
-30	.2835	838.8	11.9218	9.3287	.1337
-29	.2882	842.3	11.8730	9.5222	.1365
-28	.2930	845.7	11.8245	9.7189	.1393
-27	.2978	849.2	11.7764	9.9189	.1422
-26	.3027	852.6	11.7287	10.1222	.1451
-25	.3076	856.1	11.6815	10.3287	.1481
-24	.3126	859.5	11.6345	10.5386	.1511
-23	.3177	863.0	11.5880	10.7520	.1541
-22	.3228	866.4	11.5418	10.9687	.1572
-21	.3279	869.9	11.4960	11.1890	.1604
-20	.3332	873.3	11.4506	11.4128	.1636
-19	.3385	876.8	11.4055	11.6401	.1669
-18	.3438	880.2	11.3608	11.8711	.1702
-17	.3493	883.7	11.3164	12.1057	.1735
-16	.3548	887.1	11.2724	12.3440	.1770
-15	.3603	890.6	11.2287	12.5860	.1804
-14	.3659	894.0	11.1853	12.8318	.1839
-13	.3716	897.5	11.1423	13.0814	.1875
-12	.3774	900.9	11.0996	13.3350	.1912
-11	.3832	904.4	11.0573	13.5924	.1948
-10	.3891	907.8	11.0152	13.8537	.1986
-9	.3950	911.3	10.9735	14.1191	.2024
-8	.4010	914.7	10.9321	14.3886	.2063
-7	.4071	918.2	10.8910	14.6621	.2102
-6	.4133	921.6	10.8502	14.9398	.2142
-5	.4195	925.1	10.8097	15.2217	.2182
-4	.4258	928.5	10.7695	15.5078	.2223
-3	.4322	932.0	10.7296	15.7982	.2265
-2	.4386	935.5	10.6900	16.0929	.2307
-1	.4451	938.9	10.6507	16.3920	.2350
0	.4517	942.4	10.6117	16.6956	.2393
1	.4584	945.8	10.5730	17.0036	.2437
2	.4651	949.3	10.5345	17.3162	.2482
3	.4719	952.7	10.4964	17.6333	.2528
4	.4788	956.2	10.4585	17.9551	.2574
5	.4857	959.6	10.4209	18.2815	.2621
6	.4927	963.1	10.3835	18.6127	.2668
7	.4998	966.5	10.3464	18.9487	.2716
8	.5070	970.0	10.3096	19.2895	.2765
9	.5143	973.4	10.2730	19.6351	.2815

Continued on next page

Table 5 continued

Temperature: (°C)	W	$\nu$ max	$\lambda$ max	$W_{\max}$	$W_{\max}$
	$\text{cm}^{-2} \text{ min}^{-1}$	Wave number $\text{cm}^{-1}$	$\mu$	$\frac{\text{Erg cm}^{-2}}{\text{sec}^{-1} \text{ cm}^{-1}} \times 10^7$	$\frac{\text{Cal cm}^{-2}}{\text{min}^{-1} \mu^{-1}} \times 10^{-1}$
10	0.5216	976.9	10.2367	19.9858	0.2865
11	.5290	980.3	10.2007	20.3414	.2916
12	.5365	983.8	10.1649	20.7020	.2968
13	.5441	987.2	10.1294	21.0678	.3020
14	.5517	990.7	10.0941	21.4387	.3073
15	.5595	994.1	10.0590	21.8148	.3127
16	.5673	997.6	10.0242	22.1961	.3182
17	.5752	1,001.0	9.9897	22.5829	.3237
18	.5831	1,004.5	9.9553	22.9749	.3293
19	.5912	1,007.9	9.9212	23.3724	.3350
20	.5993	1,011.4	9.8874	23.7753	.3408
21	.6076	1,014.8	9.8537	24.1838	.3467
22	.6159	1,018.3	9.8203	24.5979	.3526
23	.6243	1,021.7	9.7872	25.0177	.3586
24	.6327	1,025.2	9.7542	25.4431	.3647
25	.6413	1,028.7	9.7215	25.8744	.3709
26	.6500	1,032.1	9.6890	26.3115	.3772
27	.6587	1,035.6	9.6567	26.7544	.3835
28	.6675	1,039.0	9.6246	27.2033	.3900
29	.6764	1,042.5	9.5927	27.6582	.3965
30	.6854	1,045.9	9.5611	28.1191	.4031
31	.6945	1,049.4	9.5296	28.5862	.4098
32	.7037	1,052.8	9.4984	29.0595	.4166
33	.7130	1,056.3	9.4673	29.5390	.4234
34	.7224	1,059.7	9.4365	30.0248	.4304
35	.7318	1,063.2	9.4058	30.5170	.4375
36	.7414	1,066.6	9.3754	31.0157	.4446
37	.7510	1,070.1	9.3452	31.5208	.4519
38	.7607	1,073.5	9.3151	32.0325	.4592
39	.7706	1,077.0	9.2853	32.5508	.4666
40	.7805	1,080.4	9.2556	33.0758	.4741
41	.7905	1,083.9	9.2261	33.6075	.4818
42	.8006	1,087.3	9.1968	34.1461	.4895
43	.8109	1,090.8	9.1677	34.6916	.4973
44	.8212	1,094.2	9.1388	35.2440	.5052
45	.8316	1,097.7	9.1101	35.8034	.5132
46	.8421	1,101.1	9.0815	36.3699	.5214
47	.8527	1,104.6	9.0531	36.9435	.5296
48	.8634	1,108.0	9.0249	37.5244	.5379
49	.8742	1,111.5	8.9969	38.1125	.5464
50	.8851	1,114.9	8.9690	38.7080	.5549
51	.8961	1,118.4	8.9414	39.3110	.5635
52	.9073	1,121.9	8.9138	39.9213	.5723
53	.9185	1,125.3	8.8865	40.5393	.5811
54	.9298	1,128.5	8.8593	41.1649	.5901
55	.9412	1,132.2	8.8323	41.7982	.5992
56	.9528	1,135.7	8.8055	42.4393	.6084
57	.9644	1,139.1	8.7788	43.0882	.6177
58	.9761	1,142.6	8.7523	43.7450	.6271
59	.9880	1,146.0	8.7259	44.4098	.6366

Continued on next page

Table 5 continued

Temperature: (°C)	W	$\nu$ max	$\lambda$ max	$W_{\max}$	$W_{\max}$
	$\text{Cal cm}^{-2} \text{ min}^{-1}$	Wave number $\text{cm}^{-1}$	$\mu$	$\text{Erg sec}^{-1} \text{ cm}^{-2} \times 10^7$	$\text{Cal cm}^{-2} \text{ min}^{-1} \mu^{-1} \times 10^{-1}$
60	0.9999	1,149.5	8.6997	45.0827	0.6463
61	1.0120	1,152.9	8.6737	45.7637	.6560
62	1.0242	1,156.4	8.6478	46.4529	.6659
63	1.0365	1,159.8	8.6220	47.1503	.6759
64	1.0489	1,163.3	8.5964	47.8562	.6860
65	1.0614	1,166.7	8.5710	48.5704	.6963
66	1.0740	1,170.2	8.5457	49.2932	.7066
67	1.0867	1,173.6	8.5206	50.0246	.7171
68	1.0995	1,177.1	8.4956	50.7645	.7277
69	1.1125	1,180.5	8.4708	51.5133	.7385
70	1.1256	1,184.0	8.4461	52.2708	.7493
71	1.1388	1,187.4	8.4215	53.0372	.7603
72	1.1521	1,190.9	8.3971	53.8126	.7714
73	1.1655	1,194.3	8.3728	54.5970	.7827
74	1.1790	1,197.8	8.3487	55.3906	.7940
75	1.1927	1,201.2	8.3247	56.1933	.8055
76	1.2064	1,204.7	8.3009	57.0054	.8172
77	1.2203	1,208.1	8.2771	57.8267	.8290
78	1.2343	1,211.6	8.2536	58.6576	.8409
79	1.2484	1,215.1	8.2301	59.4979	.8529
80	1.2627	1,218.5	8.2068	60.3479	.8651
81	1.2771	1,222.0	8.1836	61.2075	.8774
82	1.2915	1,225.4	8.1606	62.0770	.8899
83	1.3062	1,228.9	8.1376	62.9561	.9025
84	1.3209	1,232.3	8.1148	63.8454	.9152
85	1.3358	1,235.8	8.0922	64.7446	.9281
86	1.3508	1,239.2	8.0696	65.6539	.9412
87	1.3659	1,242.7	8.0472	66.5734	.9543
88	1.3811	1,246.1	8.0249	67.5032	.9677
89	1.3965	1,249.6	8.0028	68.4434	.9812
90	1.4120	1,253.0	7.9807	69.3939	.9948
91	1.4276	1,256.5	7.9588	70.3551	1.0086
92	1.4433	1,260.0	7.9370	71.3268	1.0225
93	1.4592	1,263.4	7.9153	72.3093	1.0366
94	1.4752	1,266.8	7.8937	73.3025	1.0508
95	1.4914	1,270.3	7.8723	74.3067	1.0652
96	1.5077	1,273.7	7.8509	75.3217	1.0798
97	1.5241	1,277.2	7.8297	76.3479	1.0945
98	1.5406	1,280.6	7.8086	77.3852	1.1093
99	1.5573	1,284.1	7.7876	78.4338	1.1244
100	1.5741	1,287.5	7.7668	79.4937	1.1396

### Atmospheric Radiation--Empirical Formulas

Empirical equations for estimating clear-sky atmospheric radiation differ primarily on the inclusion of a water vapor factor. Table 6 presents the Brunt equation, which includes a water vapor factor:

$$I_{\downarrow} = \sigma T^4 (a + b\sqrt{e})$$

where  $I_{\downarrow}$  is the long-wave sky radiation in  $\text{cal cm}^{-2} \text{ min}^{-1}$ ,  $\sigma$  is the Stefan-Boltzmann constant ( $8.132 \times 10^{-11} \text{ cal cm}^{-2} \text{ min}^{-1} \text{ }^{\circ}\text{K}^{-4}$ ),  $T$  is the screen-height air temperature ( $^{\circ}\text{K}$ ),  $a$  and  $b$  are constants with values of 0.660 and 0.039 respectively, and  $e$  is the screen-height vapor pressure in millibars. The values in table 6 are presented in terms of screen-height air temperature in  $^{\circ}\text{C}$  and screen-height relative humidity.

Table 6.--Brunt equation,  $I_+ = \sigma T^4 (a + b\sqrt{e})$ , for atmospheric radiation

(In  $\text{cal cm}^{-2} \text{min}^{-1}$ )

°C	Percent relative humidity											
	100	90	80	70	60	50	40	30	20	10	1	
-40	0.1622	0.1620	0.1618	0.1616	0.1613	0.1611	0.1608	0.1604	0.1600	0.1595	0.1586	
-39	.1653	.1650	.1648	.1646	.1643	.1640	.1637	.1633	.1629	.1623	.1614	
-38	.1683	.1681	.1679	.1676	.1673	.1670	.1666	.1662	.1658	.1652	.1642	
-37	.1715	.1712	.1710	.1707	.1704	.1700	.1696	.1692	.1687	.1681	.1670	
-36	.1747	.1744	.1741	.1738	.1735	.1731	.1727	.1723	.1717	.1710	.1699	
-35	.1779	.1776	.1773	.1770	.1766	.1762	.1758	.1753	.1748	.1740	.1728	
-34	.1812	.1809	.1806	.1802	.1798	.1794	.1790	.1785	.1778	.1770	.1757	
-33	.1846	.1842	.1839	.1835	.1831	.1827	.1822	.1816	.1810	.1801	.1787	
-32	.1880	.1876	.1873	.1869	.1864	.1860	.1854	.1849	.1842	.1832	.1817	
-31	.1915	.1911	.1907	.1903	.1898	.1893	.1888	.1881	.1874	.1864	.1848	
-30	.1950	.1946	.1942	.1937	.1933	.1927	.1921	.1915	.1907	.1896	.1879	
-29	.1986	.1982	.1978	.1973	.1967	.1962	.1956	.1948	.1940	.1929	.1911	
-28	.2023	.2019	.2014	.2009	.2003	.1997	.1990	.1983	.1974	.1962	.1943	
-27	.2061	.2056	.2051	.2045	.2039	.2033	.2026	.2018	.2008	.1996	.1975	
-26	.2099	.2094	.2088	.2082	.2076	.2069	.2062	.2053	.2043	.2030	.2008	
-25	.2138	.2132	.2127	.2120	.2114	.2106	.2098	.2089	.2078	.2064	.2041	
-24	.2178	.2172	.2166	.2159	.2152	.2144	.2136	.2126	.2114	.2099	.2075	
-23	.2218	.2212	.2205	.2198	.2191	.2183	.2174	.2163	.2151	.2135	.2109	
-22	.2259	.2253	.2246	.2238	.2230	.2222	.2212	.2201	.2188	.2171	.2143	
-21	.2302	.2295	.2287	.2279	.2271	.2261	.2251	.2240	.2226	.2208	.2178	
-20	.2345	.2337	.2323	.2321	.2312	.2302	.2291	.2279	.2264	.2245	.2214	
-19	.2388	.2380	.2372	.2363	.2353	.2343	.2332	.2318	.2303	.2283	.2249	
-18	.2433	.2425	.2416	.2406	.2396	.2385	.2373	.2359	.2342	.2321	.2286	
-17	.2478	.2470	.2460	.2450	.2439	.2428	.2415	.2400	.2383	.2360	.2322	
-16	.2525	.2516	.2506	.2495	.2484	.2471	.2457	.2442	.2423	.2399	.2360	
-15	.2572	.2562	.2552	.2541	.2529	.2515	.2501	.2484	.2465	.2439	.2397	
-14	.2621	.2610	.2599	.2587	.2574	.2561	.2545	.2528	.2507	.2480	.2436	
-13	.2670	.2659	.2647	.2635	.2621	.2606	.2590	.2572	.2550	.2521	.2474	
-12	.2721	.2709	.2696	.2683	.2669	.2653	.2636	.2617	.2593	.2563	.2514	
-11	.2772	.2760	.2746	.2732	.2717	.2701	.2683	.2662	.2638	.2606	.2553	
-10	.2825	.2811	.2800	.2789	.2767	.2749	.2730	.2708	.2683	.2649	.2593	
-9	.2878	.2864	.2850	.2834	.2817	.2799	.2779	.2756	.2728	.2693	.2634	
-8	.2933	.2918	.2903	.2886	.2869	.2849	.2828	.2804	.2775	.2737	.2675	
-7	.2989	.2974	.2957	.2940	.2921	.2901	.2878	.2852	.2822	.2783	.2717	
-6	.3046	.3030	.3013	.2994	.2974	.2953	.2929	.2902	.2870	.2828	.2760	
-5	.3105	.3087	.3069	.3050	.3029	.3006	.2981	.2953	.2919	.2875	.2802	
-4	.3164	.3146	.3127	.3107	.3085	.3061	.3034	.3004	.2969	.2922	.2846	
-3	.3225	.3206	.3186	.3164	.3141	.3116	.3088	.3057	.3019	.2970	.2890	
-2	.3288	.3268	.3246	.3224	.3199	.3173	.3143	.3110	.3070	.3019	.2934	
-1	.3351	.3330	.3308	.3284	.3258	.3230	.3199	.3164	.3123	.3069	.2979	
0	.3417	.3394	.3371	.3345	.3318	.3289	.3257	.3220	.3176	.3119	.3025	
1	.3483	.3460	.3435	.3408	.3380	.3349	.3315	.3276	.3230	.3170	.3071	
2	.3551	.3527	.3500	.3473	.3443	.3410	.3374	.3333	.3285	.3222	.3118	
3	.3621	.3595	.3567	.3538	.3507	.3473	.3435	.3392	.3341	.3275	.3165	
4	.3692	.3665	.3636	.3605	.3572	.3536	.3497	.3451	.3398	.3328	.3213	
5	.3765	.3736	.3706	.3674	.3639	.3601	.3559	.3512	.3456	.3383	.3262	
6	.3840	.3809	.3778	.3744	.3707	.3667	.3624	.3574	.3515	.3438	.3311	
7	.3916	.3884	.3851	.3815	.3777	.3735	.3689	.3637	.3575	.3494	.3363	
8	.3994	.3961	.3925	.3888	.3848	.3804	.3756	.3701	.3636	.3551	.3411	
9	.4074	.4039	.4002	.3963	.3920	.3874	.3824	.3766	.3698	.3609	.3462	
10	.4155	.4119	.4080	.4039	.3995	.3947	.3893	.3833	.3761	.3668	.3514	
11	.4239	.4200	.4160	.4117	.4070	.4020	.3964	.3901	.3826	.3728	.3566	
12	.4324	.4284	.4242	.4196	.4148	.4095	.4036	.3970	.3891	.3789	.3619	
13	.4412	.4370	.4325	.4278	.4227	.4171	.4110	.4041	.3958	.3851	.3673	
14	.4501	.4457	.4411	.4361	.4308	.4250	.4185	.4112	.4026	.3913	.3727	

Continued on next page

Table 6 continued

Table 6 continued												
°C	Percent relative humidity											
	100	90	80	70	60	50	40	30	20	10	1	
15	0.4593	0.4547	0.4498	0.4446	0.4390	0.4329	0.4262	0.4186	0.4095	0.3977	0.3782	
16	.4687	.4639	.4588	.4533	.4475	.4411	.4340	.4261	.4166	.4042	.3838	
17	.4783	.4733	.4679	.4622	.4561	.4494	.4420	.4337	.4238	.4108	.3895	
18	.4882	.4829	.4773	.4713	.4649	.4579	.4502	.4414	.4311	.4175	.3952	
19	.4982	.4927	.4868	.4806	.4739	.4666	.4585	.4494	.4385	.4244	.4010	
20	.5086	.5028	.4966	.4901	.4831	.4755	.4670	.4575	.4461	.4313	.4069	
21	.5191	.5131	.5067	.4998	.4925	.4845	.4757	.4657	.4538	.4383	.4128	
22	.5300	.5236	.5169	.5098	.5021	.4938	.4846	.4741	.4617	.4455	.4188	
23	.5410	.5344	.5274	.5200	.5120	.5032	.4936	.4827	.4697	.4528	.4253	
24	.5524	.5455	.5382	.5304	.5220	.5129	.5028	.4914	.4779	.4602	.4311	
25	.5640	.5568	.5492	.5410	.5323	.5228	.5123	.5004	.4862	.4678	.4373	
26	.5759	.5684	.5604	.5519	.5428	.5329	.5219	.5095	.4947	.4754	.4437	
27	.5881	.5802	.5719	.5631	.5535	.5432	.5317	.5187	.5033	.4832	.4501	
28	.6006	.5924	.5837	.5745	.5645	.5537	.5418	.5282	.5121	.4912	.4566	
29	.6134	.6048	.5958	.5861	.5758	.5645	.5520	.5379	.5211	.4992	.4631	
30	.6265	.6176	.6081	.5981	.5873	.5755	.5625	.5478	.5303	.5075	.4698	
31	.6399	.6306	.6208	.6103	.5990	.5868	.5732	.5578	.5396	.5158	.4765	
32	.6537	.6440	.6337	.6228	.6110	.5983	.5841	.5681	.5491	.5243	.4834	
33	.6678	.6577	.6470	.6356	.6233	.6100	.5953	.5786	.5588	.5329	.4903	
34	.6822	.6717	.6605	.6487	.6359	.6221	.6067	.5893	.5686	.5417	.4973	
35	.6970	.6860	.6744	.6621	.6488	.6343	.6184	.6002	.5787	.5507	.5044	
36	.7122	.7007	.6887	.6758	.6619	.6469	.6303	.6114	.5890	.5598	.5116	
37	.7277	.7158	.7032	.6898	.6754	.6597	.6424	.6228	.5994	.5690	.5189	
38	.7436	.7312	.7181	.7042	.6892	.6729	.6548	.6344	.6101	.5785	.5262	
39	.7599	.7470	.7334	.7188	.7033	.6863	.6675	.6462	.6210	.5881	.5337	
40	.7766	.7632	.7490	.7339	.7176	.7000	.6805	.6583	.6321	.5978	.5413	
41	.7937	.7797	.7650	.7493	.7324	.7140	.6937	.6707	.6434	.6077	.5489	
42	.8112	.7967	.7814	.7650	.7475	.7284	.7073	.6833	.6549	.6179	.5567	
43	.8292	.8141	.7981	.7811	.7629	.7430	.7211	.6962	.6666	.6281	.5646	
44	.8475	.8319	.8153	.7976	.7787	.7568	.7352	.7093	.6786	.6386	.5725	
45	.8664	.8501	.8328	.8145	.7948	.7734	.7497	.7228	.6908	.6493	.5806	
46	.8857	.8687	.8508	.8318	.8113	.7890	.7644	.7365	.7033	.6601	.5888	
47	.9054	.8878	.8693	.8495	.8282	.8051	.7795	.7505	.7160	.6711	.5971	
48	.9257	.9074	.8881	.8676	.8455	.8215	.7949	.7647	.7290	.6824	.6054	
49	.9464	.9274	.9074	.8861	.8631	.8382	.8106	.7793	.7422	.6938	.6139	
50	.9677	.9480	.9272	.9050	.8812	.8553	.8267	.7942	.7557	.7054	.6225	

In table 7 the long-wave clear-sky radiation has been derived solely from screen-height air temperature as calculated by the Idso-Jackson formula (Idso and Jackson 1969):

$$I_{\downarrow} = \sigma T^4 \{1.0 - 0.261 \exp [-7.77 \times 10^{-4} (273 - T)^2]\}$$

where  $I_{\downarrow}$  is the clear-sky radiation in  $\text{cal cm}^{-2} \text{min}^{-1}$ ,  $\sigma$  is the Stefan-Boltzmann constant, and  $T$  is the screen-height air temperature in  $^{\circ}\text{K}$ . The values presented in table 7 have been supplied by S. B. Idso<sup>1</sup> and were calculated with a  $\sigma$  value of  $8.17 \times 10^{-11} \text{ cal cm}^{-2} \text{min}^{-1} \text{ } ^{\circ}\text{K}^{-4}$ .

<sup>1</sup>Personal communication with S. B. Idso.

Table 7.--Idso-Jackson formula,  $I_{\downarrow} = \sigma T^4 \{1.0 - 0.261 \exp [-7.77 \times 10^{-4} (273 - T)^2]\}$ , for atmospheric radiation

(In cal cm<sup>-2</sup> min<sup>-1</sup>)

°C	°K	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
-40	233	0.222	0.222	0.222	0.222	0.221	0.221	0.221	0.220	0.220	0.220
-39	234	.225	.225	.225	.224	.224	.224	.223	.223	.223	.223
-38	235	.228	.227	.227	.227	.227	.226	.226	.226	.226	.225
-37	236	.230	.230	.230	.230	.229	.229	.229	.229	.228	.228
-36	237	.233	.233	.232	.232	.232	.232	.231	.231	.231	.231
-35	238	.235	.235	.235	.235	.234	.234	.234	.234	.233	.233
-34	239	.238	.238	.237	.237	.237	.237	.236	.236	.236	.236
-33	240	.240	.240	.240	.240	.239	.239	.239	.239	.238	.238
-32	241	.243	.243	.242	.242	.242	.242	.241	.241	.241	.241
-31	242	.245	.245	.245	.245	.244	.244	.244	.244	.243	.243
-30	243	.248	.247	.247	.247	.247	.247	.246	.246	.246	.246
-29	244	.250	.250	.250	.249	.249	.249	.249	.248	.248	.248
-28	245	.252	.252	.252	.252	.252	.251	.251	.251	.251	.250
-27	246	.255	.254	.254	.254	.254	.254	.253	.253	.253	.253
-26	247	.257	.257	.256	.256	.256	.256	.256	.255	.255	.255
-25	248	.259	.259	.259	.259	.258	.258	.258	.258	.257	.257
-24	249	.261	.261	.261	.261	.261	.260	.260	.260	.260	.259
-23	250	.264	.263	.263	.263	.263	.263	.262	.262	.262	.262
-22	251	.266	.266	.265	.265	.265	.265	.265	.264	.264	.264
-21	252	.268	.268	.268	.268	.267	.267	.267	.267	.266	.266
-20	253	.270	.270	.270	.270	.270	.269	.269	.269	.269	.268
-19	254	.273	.273	.272	.272	.272	.272	.271	.271	.271	.271
-18	255	.275	.275	.275	.274	.274	.274	.274	.273	.273	.273
-17	256	.277	.277	.277	.277	.277	.276	.276	.276	.276	.275
-16	257	.280	.280	.279	.279	.279	.279	.278	.278	.278	.278
-15	258	.282	.282	.282	.282	.281	.281	.281	.281	.280	.280
-14	259	.285	.285	.284	.284	.284	.284	.283	.283	.283	.283
-13	260	.288	.287	.287	.287	.287	.286	.286	.286	.286	.285
-12	261	.290	.290	.290	.290	.289	.289	.289	.288	.288	.288
-11	262	.293	.293	.293	.292	.292	.292	.291	.291	.291	.291
-10	263	.296	.296	.296	.295	.295	.295	.294	.294	.294	.294
-9	264	.299	.299	.299	.298	.298	.298	.297	.297	.297	.296
-8	265	.303	.302	.302	.302	.301	.301	.301	.300	.300	.300
-7	266	.306	.306	.305	.305	.305	.304	.304	.304	.303	.303
-6	267	.309	.309	.309	.308	.308	.308	.307	.307	.307	.306
-5	268	.313	.313	.312	.312	.312	.311	.311	.311	.310	.310
-4	269	.317	.317	.316	.316	.316	.315	.315	.314	.314	.314
-3	270	.321	.321	.320	.320	.320	.319	.319	.318	.318	.318
-2	271	.326	.325	.325	.324	.324	.323	.323	.323	.322	.322
-1	272	.330	.330	.329	.329	.328	.328	.327	.327	.326	.326
-0	273	.335	.334	.334	.333	.333	.332	.332	.332	.331	.331
+0	273	.335	.336	.336	.337	.337	.338	.338	.339	.339	.340
1	274	.340	.341	.341	.342	.342	.343	.344	.344	.345	.345
2	275	.346	.346	.347	.347	.348	.349	.349	.350	.350	.351
3	276	.351	.352	.352	.353	.353	.354	.355	.355	.356	.356
4	277	.357	.358	.358	.359	.359	.360	.361	.361	.362	.362
5	278	.363	.364	.364	.365	.366	.366	.367	.367	.368	.369
6	279	.369	.370	.371	.371	.372	.373	.373	.374	.375	.375
7	280	.376	.377	.377	.378	.379	.379	.380	.381	.381	.382
8	281	.383	.384	.384	.385	.386	.386	.387	.388	.389	.389
9	282	.390	.391	.392	.392	.393	.394	.394	.395	.396	.397
10	283	.397	.398	.399	.400	.401	.401	.402	.403	.404	.404
11	284	.405	.406	.407	.408	.408	.409	.410	.411	.412	.412
12	285	.413	.414	.415	.416	.417	.417	.418	.419	.420	.421
13	286	.422	.422	.423	.424	.425	.426	.427	.427	.428	.429
14	287	.430	.431	.432	.433	.434	.434	.435	.436	.437	.438

Continued on next page

Table 7 continued

°C	°K	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	288	0.439	0.440	0.441	0.442	0.443	0.443	0.444	0.445	0.446	0.447
16	289	.448	.449	.450	.451	.452	.453	.454	.455	.455	.456
17	290	.457	.458	.459	.460	.461	.462	.463	.464	.465	.466
18	291	.467	.468	.469	.470	.471	.472	.473	.474	.475	.476
19	292	.477	.478	.479	.480	.481	.482	.483	.484	.485	.486
20	293	.487	.488	.489	.490	.491	.492	.493	.494	.495	.496
21	294	.297	.498	.499	.500	.502	.503	.504	.505	.506	.507
22	295	.508	.509	.510	.511	.512	.513	.514	.515	.516	.518
23	296	.519	.520	.521	.522	.523	.524	.525	.526	.527	.529
24	297	.530	.531	.532	.533	.534	.535	.536	.537	.539	.540
25	298	.541	.542	.543	.544	.545	.546	.548	.549	.550	.551
26	299	.552	.553	.554	.556	.557	.558	.559	.560	.561	.563
27	300	.564	.565	.566	.567	.568	.570	.571	.572	.573	.574
28	301	.575	.577	.578	.579	.580	.581	.583	.584	.585	.586
29	302	.587	.589	.590	.591	.592	.593	.595	.596	.597	.598
30	303	.599	.601	.602	.603	.604	.605	.607	.608	.609	.610
31	304	.611	.613	.614	.615	.616	.618	.619	.620	.621	.622
32	305	.624	.625	.626	.627	.629	.630	.631	.632	.634	.635
33	306	.636	.637	.639	.640	.641	.642	.644	.645	.646	.647
34	307	.649	.650	.651	.652	.654	.655	.656	.657	.659	.660
35	308	.661	.662	.664	.665	.666	.667	.669	.670	.671	.673
36	309	.674	.675	.676	.678	.679	.680	.681	.683	.684	.685
37	310	.687	.688	.689	.690	.692	.693	.694	.695	.697	.698
38	311	.699	.701	.702	.703	.704	.706	.707	.708	.710	.711
39	312	.712	.713	.715	.716	.717	.719	.720	.721	.723	.724
40	313	.725	.726	.728	.729	.730	.732	.733	.734	.735	.737
41	314	.738	.739	.741	.742	.743	.745	.746	.747	.748	.750
42	315	.751	.752	.754	.755	.756	.758	.759	.760	.761	.763
43	316	.764	.765	.767	.768	.769	.771	.772	.773	.775	.776
44	317	.777	.778	.780	.781	.782	.784	.785	.786	.788	.789
45	318	.790	.792	.793	.794	.796	.797	.798	.799	.801	.802
46	319	.803	.805	.806	.807	.809	.810	.811	.813	.814	.815
47	320	.817	.818	.819	.820	.822	.823	.824	.826	.827	.828
48	321	.830	.831	.832	.834	.835	.836	.838	.839	.840	.842
49	322	.843	.844	.845	.847	.848	.849	.851	.852	.853	.855

## SOLAR RADIATION

## Time Correction

The Earth is divided into 24 standard time zones, each 15° wide and extending 7½° on either side of a standard meridian. Because the Sun takes 1 hour to cross a time zone, it crosses 1° of longitude in 4 minutes. Therefore, in order to obtain "true local time" (mean solar time) it is necessary to add 4 minutes for each degree of longitude east of the standard meridian, or subtract 4 minutes for each degree of longitude west of the standard meridian.

The first standard meridian (0° longitude) passes through Greenwich, with successive meridians being multiples of 15° of longitude west of the 0° meridian of Greenwich. It should be noted that over land masses the standard time zones seldom extend exactly 7°30' from either side of the standard meridian, but rather follow geographical or political boundaries.

To obtain true (apparent) solar time it is necessary to algebraically add a correction for the "equation of time" to the true local time. These corrections are listed in table 8, in minutes (M) and seconds (S).

## Position

The overhead position of the Sun is shown in figures 1 through 6 (redrawn from List, 1968) for various latitudes. The altitude and azimuth can be determined for any time or date from these diagrams. The altitude or elevation of the Sun above the horizon, in degrees, is determined from the concentric circles, and the azimuth from the radial lines. The outer circle (0° elevation) obviously represents true sunrise or sunset, rather than apparent sunrise or sunset which is due to atmospheric refraction. Under average conditions, in the latitudes covered by these diagrams, apparent sunrise or sunset will occur when the Sun is less than 1 degree below the horizon.

All diagram times are true (apparent) solar times and must be corrected for longitude and the "equation of time" for local standard time. Thus, by selecting the appropriate diagram and Sun path line, the position of the Sun, shading, slope exposure, etc. can be determined for any time of day. Interpolation is permissible.

Table 8.--Corrections in minutes (M) and seconds (S) to obtain true solar time from equation of time

Month	Day															
	1		5		9		13		17		21		25		29	
	M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S
Jan.	-3	14	-5	6	-6	50	-8	27	-9	54	-11	10	-12	14	-13	5
Feb.	-13	34	-14	2	-14	17	-14	20	-14	10	-13	50	-13	19	--	--
March	-12	38	-11	48	-10	51	-9	49	-8	42	-7	32	-6	20	-5	7
April	-4	12	-3	1	-1	52	-0	47	+0	13	+1	6	+1	53	+2	33
May	+2	50	+3	17	+3	35	+3	44	+3	44	+3	34	+3	16	+2	51
June	+2	27	+1	49	+1	6	+0	18	-0	33	-1	25	-2	17	-3	7
July	-3	31	-4	16	-4	56	-5	30	-5	57	-6	15	-6	24	-6	23
Aug.	-6	17	-5	59	-5	33	-4	57	-4	12	-3	19	-2	18	-1	10
Sept.	-0	15	+1	2	+2	22	+3	45	+5	10	+6	35	+8	0	+9	22
Oct.	+10	1	+11	17	+12	27	+13	30	+14	25	+15	10	+15	46	+16	10
Nov.	+16	21	+16	23	+16	12	+15	47	+15	10	+14	18	+13	15	+11	59
Dec.	+11	16	+9	43	+8	1	+6	12	+4	17	+2	19	+0	20	-1	39

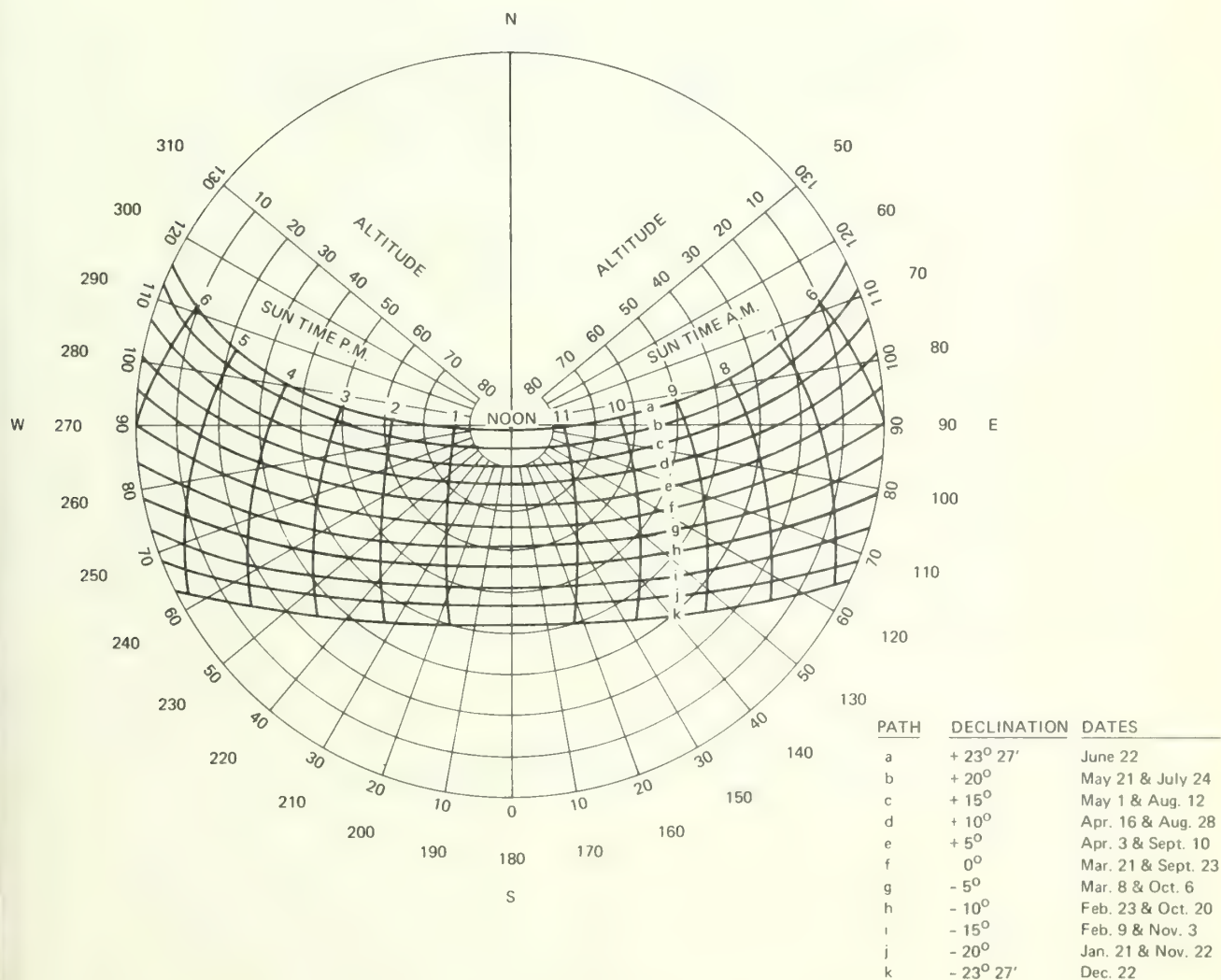


Figure 1.--Sun path diagram for 25° N. latitude.

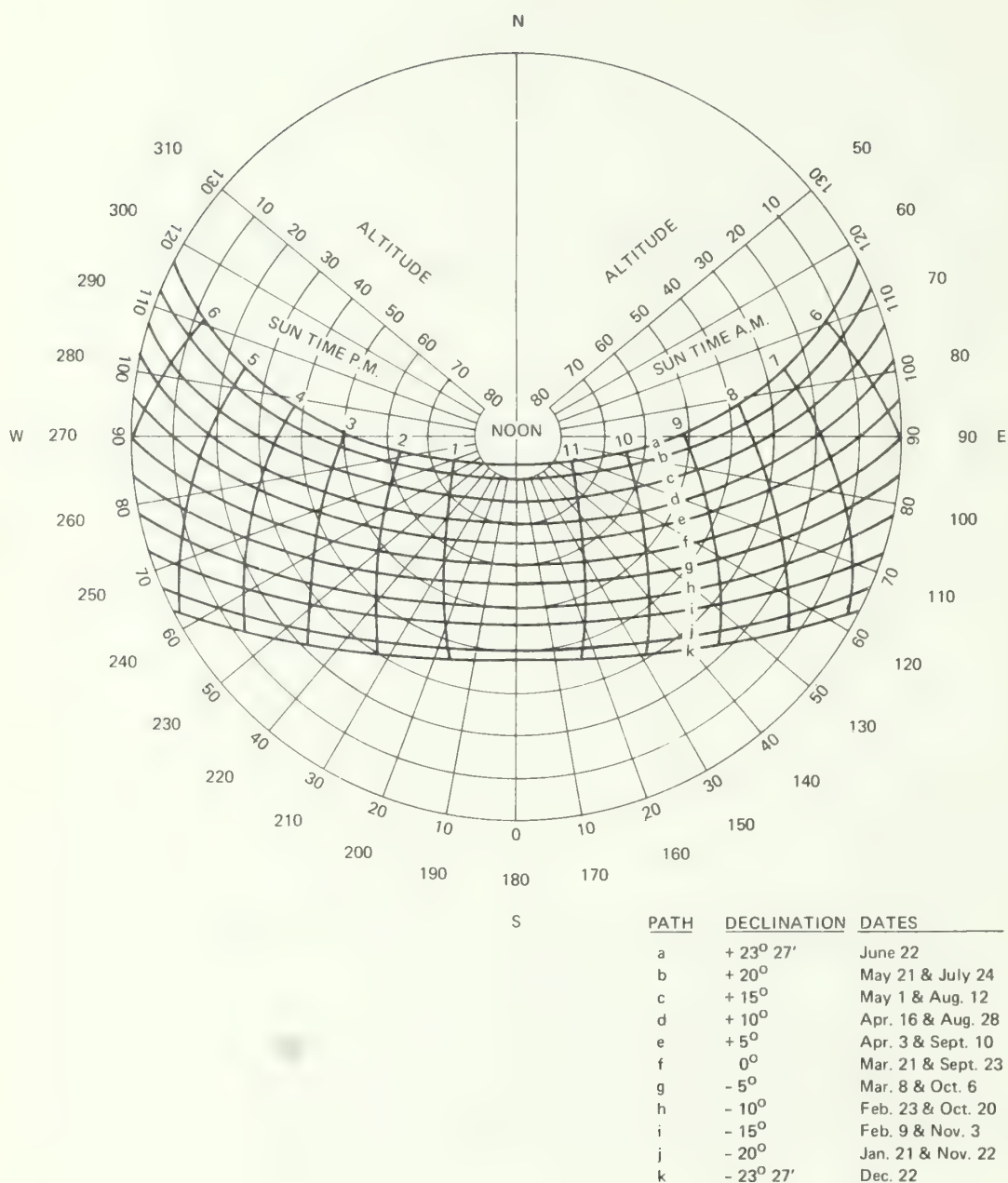


Figure 2.--Sun path diagram for 30° N. latitude.

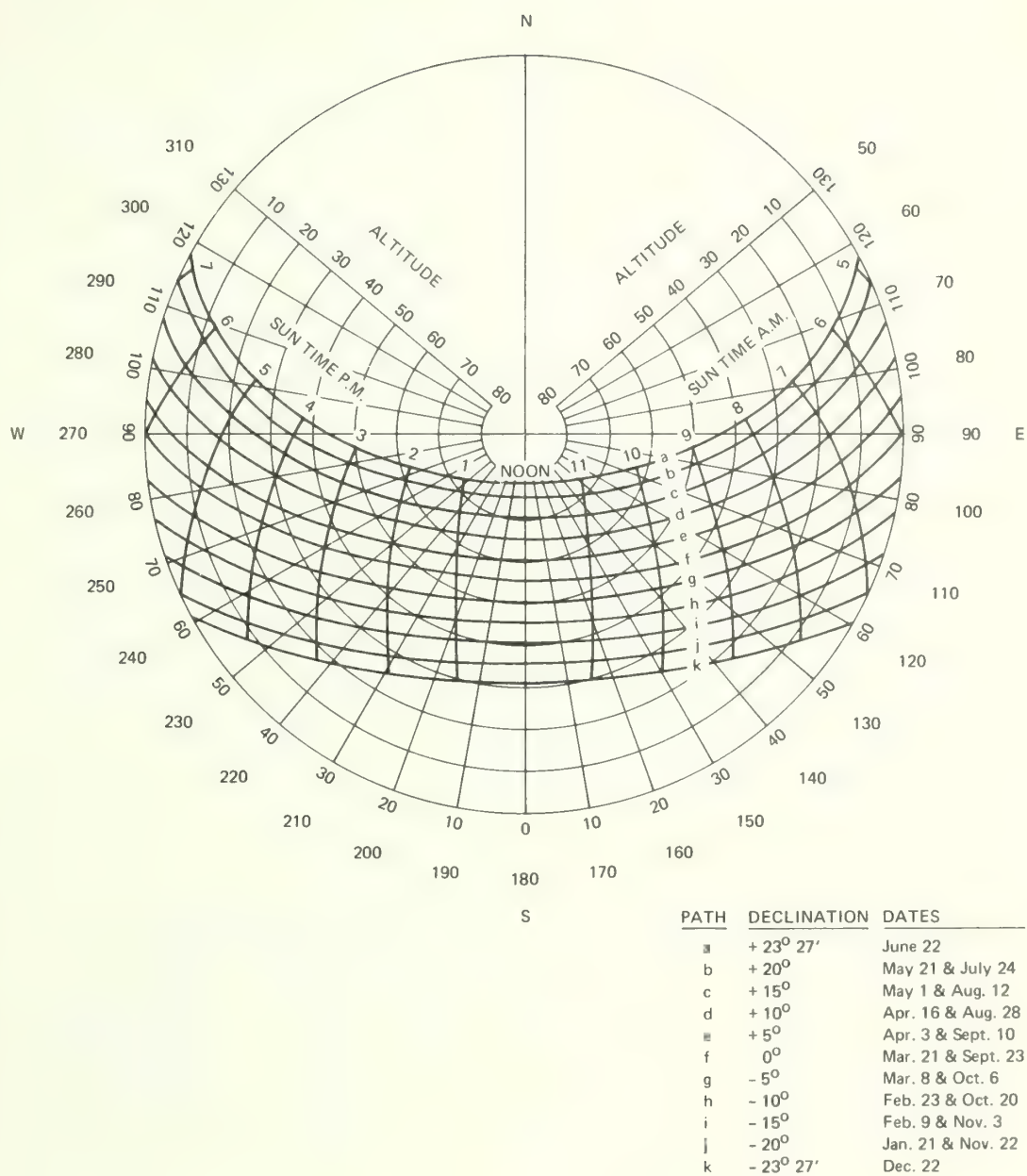


Figure 3.--Sun path diagram for 35° N. latitude.

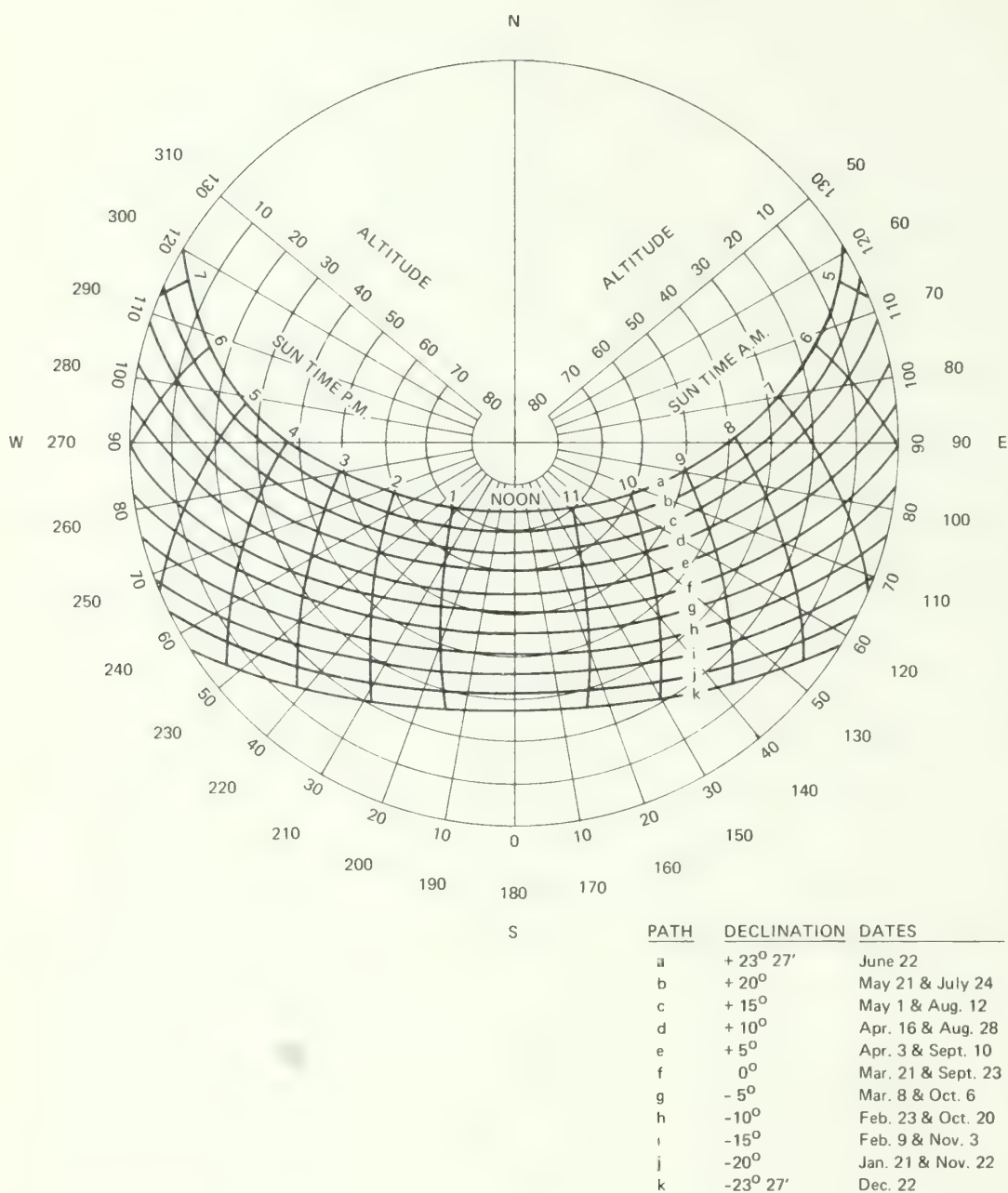
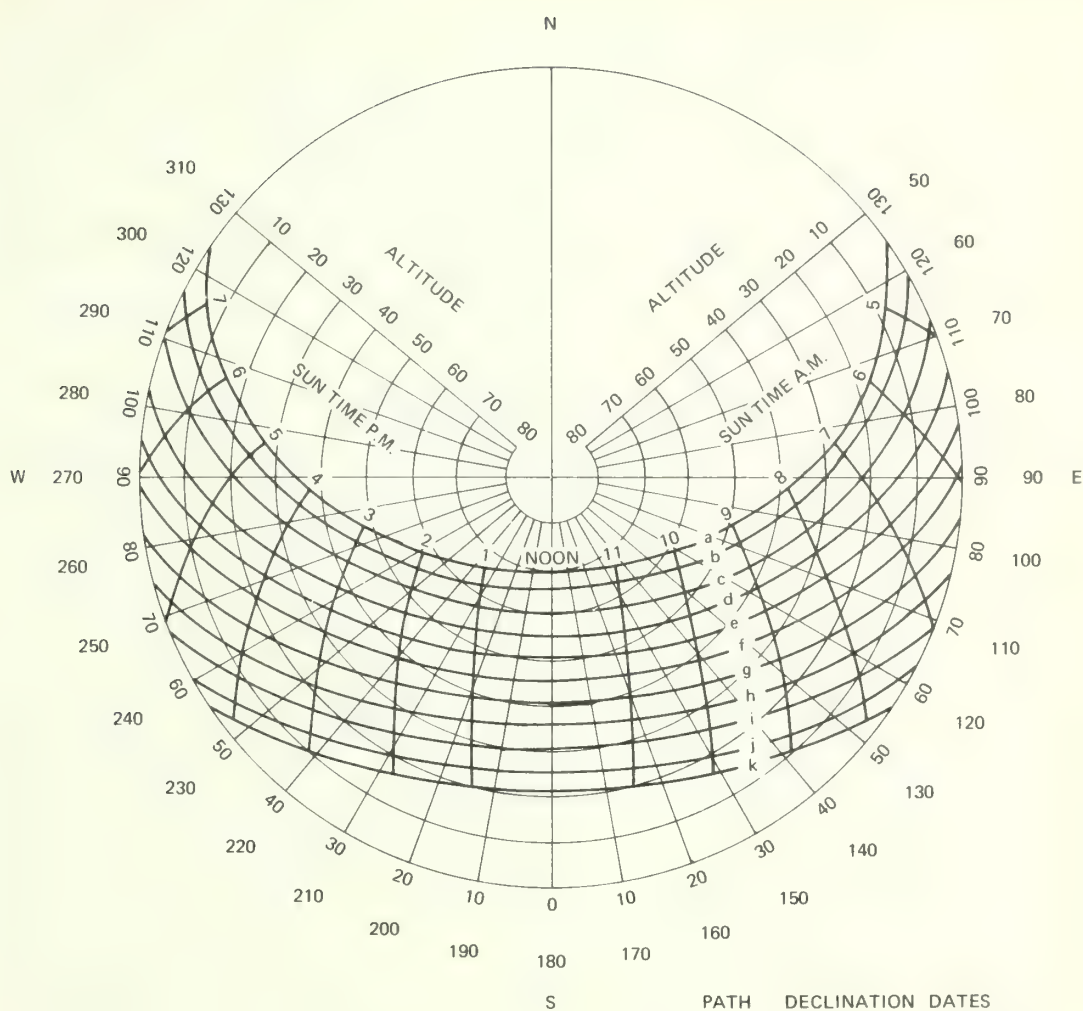


Figure 4.--Sun path diagram for 40° N. latitude.



PATH	DECLINATION	DATES
a	+ 23° 27'	June 22
b	+ 20°	May 21 & July 24
c	+ 15°	May 1 & Aug. 12
d	+ 10°	Apr. 16 & Aug. 28
e	+ 5°	Apr. 3 & Sept. 10
f	0°	Mar. 21 & Sept. 23
g	- 5°	Mar. 8 & Oct. 6
h	- 10°	Feb. 23 & Oct. 20
i	- 15°	Feb. 9 & Nov. 3
j	- 20°	Jan. 21 & Nov. 22
k	- 23° 27'	Dec. 22

Figure 5.--Sun path diagram for 45° N. latitude.

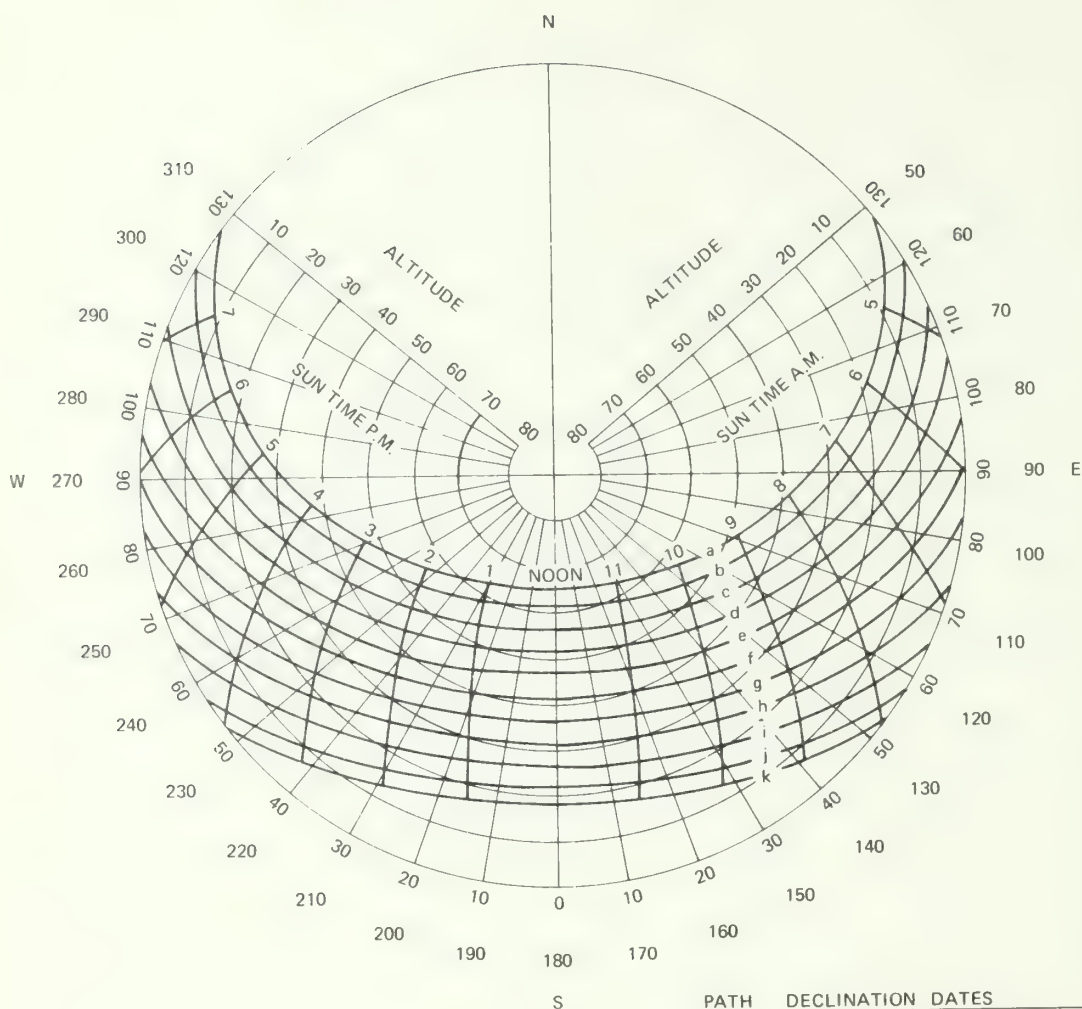


Figure 6.--Sun path diagram for 50° N. latitude.

PATH	DECLINATION	DATES
a	+ 23° 27'	June 22
b	+ 20°	May 21 & July 24
c	+ 15°	May 1 & Aug. 12
d	+ 10°	Apr. 16 & Aug. 28
e	+ 5°	Apr. 3 & Sept. 10
f	0°	Mar. 21 & Sept. 23
g	- 5°	Mar. 8 & Oct. 6
h	- 10°	Feb. 23 & Oct. 20
i	- 15°	Feb. 9 & Nov. 3
j	- 20°	Jan. 21 & Nov. 22
k	- 23° 27'	Dec. 22

### Potential Solar Radiation

The potential or amount of solar irradiation at the top of the atmosphere is shown in figure 7 for various latitudes in langley days<sup>-1</sup> (cal cm<sup>-2</sup> day<sup>-1</sup>). These data are from Frank and Lee (1966) and represent the potential radiation on a horizontal surface. By introducing factors to account for cloudiness and atmospheric turbidity, estimates of actual irradiation on a horizontal surface may be obtained. For solar irradiation on slopes see Frank and Lee (1966), Fons *et al.* (1960), and Buffo *et al.* (1972).

### Spectral Distribution

The spectral distribution of direct beam sunlight, skylight, cloudlight, and the light transmitted through vegetation is shown in figure 8 from Gates (1965). In this figure the intensity is plotted by wave number, allowing the full spectrum to be shown. The different spectral distribution of sunlight, cloudlight, skylight, and the light transmitted through vegetation may have profound ecological consequences. These factors must also be considered when using energy sensors of different spectral sensitivities.

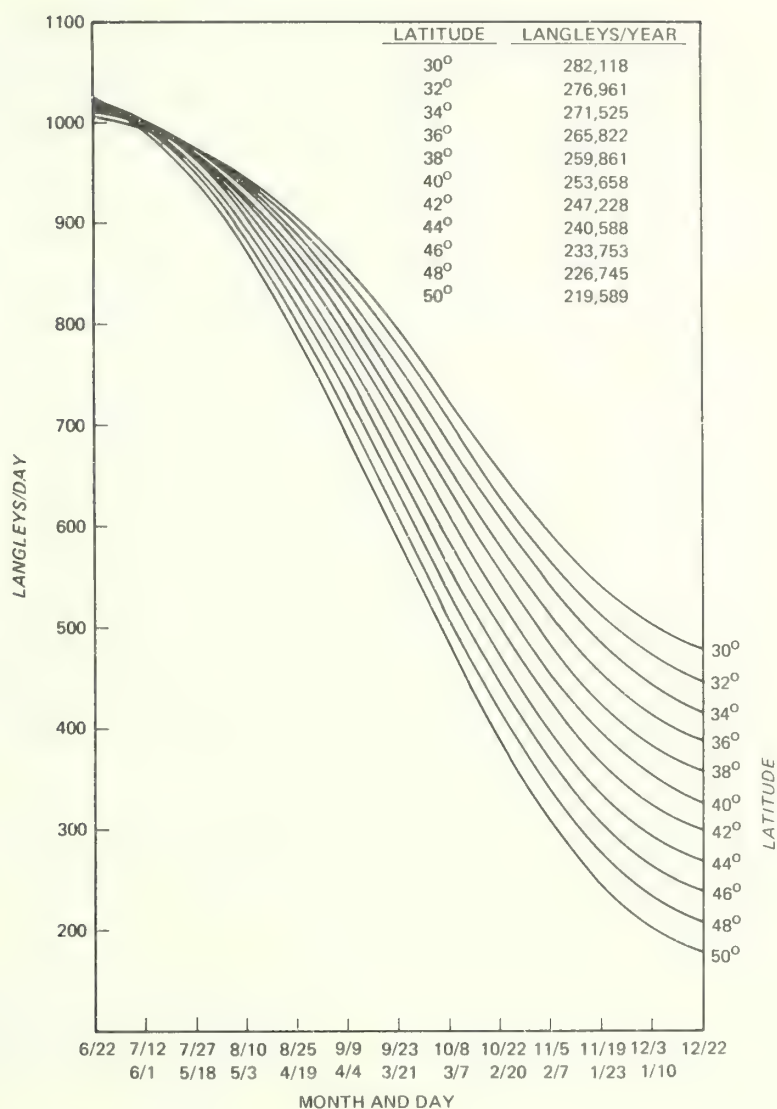


Figure 7.--Potential solar beam irradiation on a horizontal surface for various latitudes and dates.

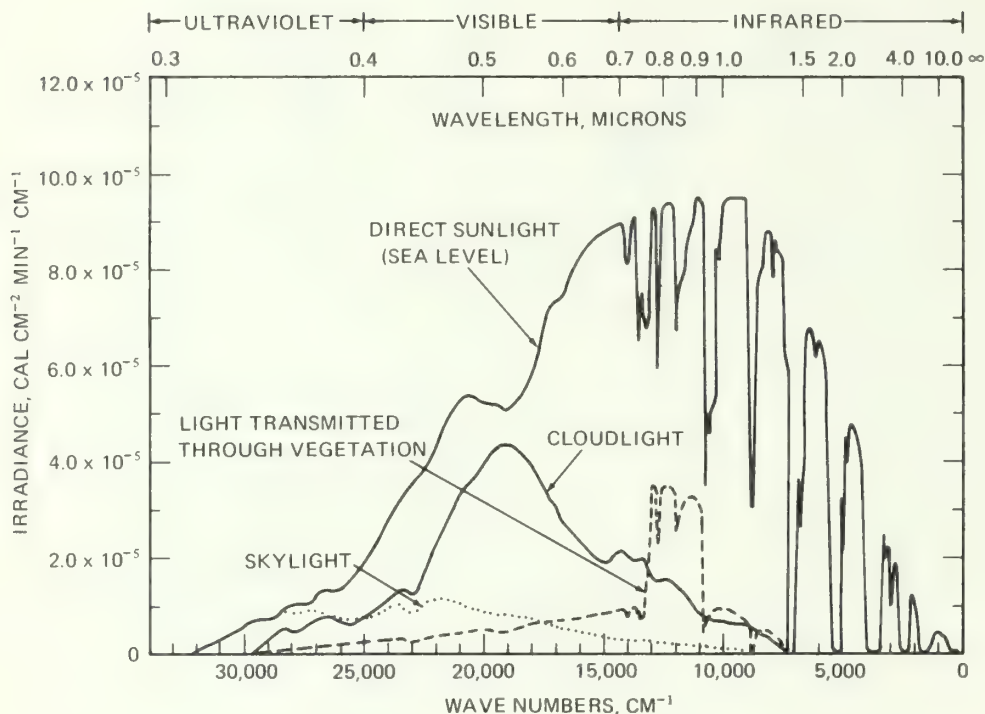


Figure 8.--Spectral distribution of direct sunlight, skylight, cloudlight, and light transmitted through vegetation as a function of the frequency of radiation in wave numbers (Gates 1965).

## WATER

A psychrometric chart (fig. 9) enables the user to determine various factors of water vapor in the air, when two factors are known. Dry bulb temperature, wet bulb temperature, relative humidity, dew point (in °C and °F), vapor pressure (in inches of mercury, millimeters of mercury, and millibars), and absolute humidity (in grams/cubic feet, grams/kilogram of air, and grams/cubic meter) are included on the chart.

Although prepared for a barometric pressure of 30 inches of mercury, the chart may be used in most cases down to a barometric pressure of 28 inches of mercury without correction.

Inches of water per pound of rain or snow can be determined for rain gauges of various diameters (fig. 10).

Volumes and weights of water per surface area by depth of precipitation are in table 9.

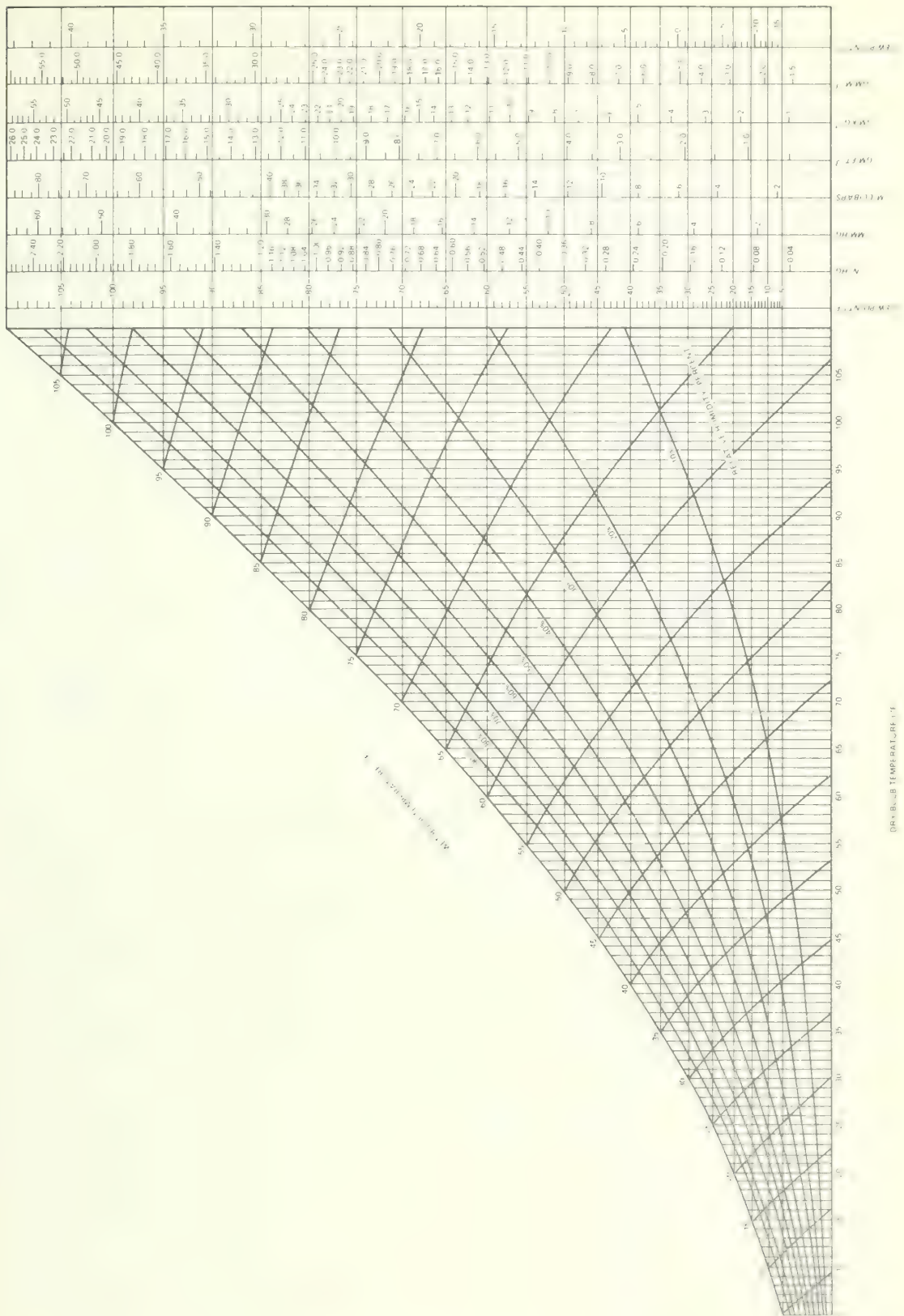


Figure 9.--Psychrometric chart (barometric pressure = 30.0 inches Hg) when any two factors are known, others may be found from the chart. Interpolate as necessary. Relative humidity may be found from the appropriate curves, at the intersection of the wet bulb and dry bulb temperatures. Dew point, vapor pressure, and absolute humidity may be determined from the horizontal lines.

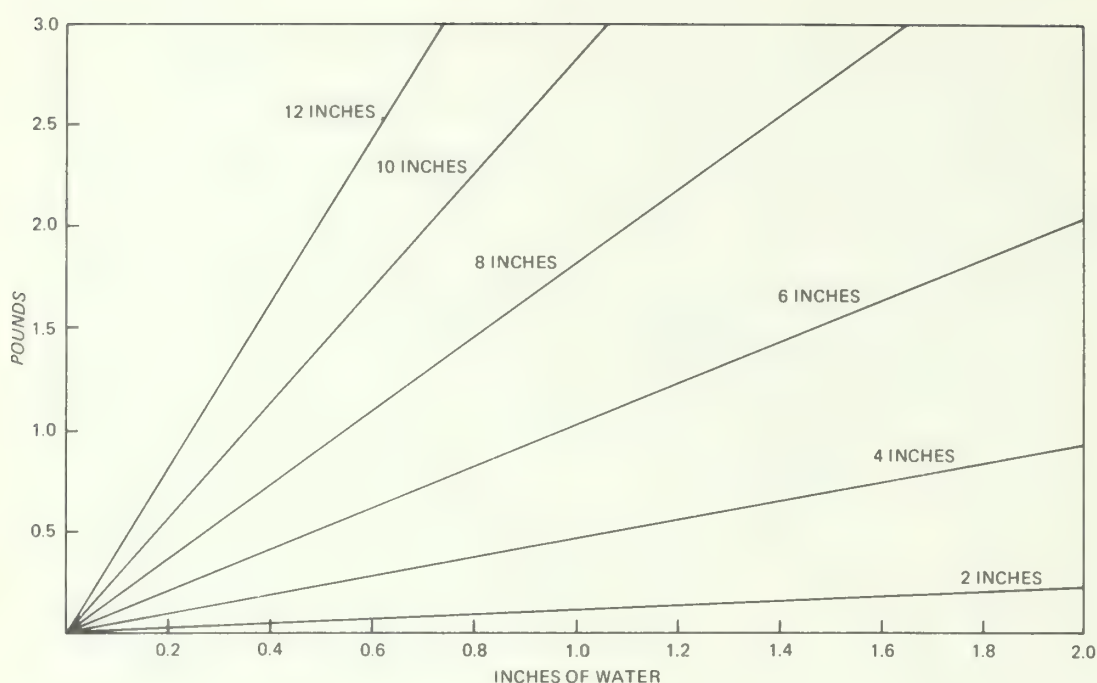


Figure 10.--Inches of water from pounds of rain or snow collected in gauges of various diameters.

Table 9.--Amounts of water by depth of precipitation

Precipitation (inches)	Gal/acre	Tons/acre	1,000 gal/mile <sup>2</sup>	Tons/mile <sup>2</sup>	Acre ft/mile <sup>2</sup>
0.01	272	1	1.7	723	0.5
.02	543	2	35	1,446	1.1
.03	815	3	52	2,170	1.6
.04	1,086	5	70	2,893	2.1
.05	1,358	6	87	3,616	2.7
.06	1,629	7	104	4,339	3.2
.07	1,901	8	122	5,062	3.7
.08	2,172	9	139	5,786	4.3
.09	2,444	10	156	6,509	4.8
.10	2,715	11	174	7,232	5.3
.20	5,431	23	348	14,464	10.7
.30	8,146	34	521	21,696	16.0
.40	10,862	45	695	28,928	21.3
.50	13,577	57	869	36,160	26.7
.60	16,292	68	1,043	43,392	32.0
.70	19,008	79	1,216	50,624	37.3
.80	21,723	91	1,390	57,856	42.7
.90	24,439	102	1,564	65,088	48.0
1.00	27,154	113	1,738	72,320	53.3
2.00	54,308	227	3,476	144,640	106.7
3.00	81,462	340	5,214	216,960	160.0
4.00	108,616	453	6,951	289,280	213.3
5.00	135,770	566	8,689	361,600	266.7
6.00	162,924	680	10,427	433,920	320.0
7.00	190,078	793	12,165	506,240	373.3
8.00	217,232	906	13,903	578,560	426.7
9.00	244,386	1,019	15,641	650,880	480.0

# CONVERSION FACTORS

CONVERSION FACTORS

Angle			To Convert	Into	Multiply by
To Convert	Into	Multiply by			
degrees	min	60.0	sq ft (contd)	sq miles	$3.587 \times 10^{-8}$
	quadrants	0.01111		sq mm	$9.290 \times 10^4$
	radians	0.01745		sq rods	$3.67309 \times 10^{-3}$
	sec	3,600.0		sq yd	0.1111
min	degrees	0.01667	sq in.	sq chains	$1.59423 \times 10^{-6}$
	quadrants	$1.852 \times 10^{-4}$		sq cm	6.451626
	radians	$2.909 \times 10^{-4}$		sq ft	$6.9444 \times 10^{-3}$
	sec	60.0		sq links	0.0159423
				sq m	$6.451626 \times 10^{-4}$
quadrants	degrees	90.0	sq mm	sq mm	645.1626
	min	5400.0		sq yd	$7.716 \times 10^{-4}$
	radians	1.571			
	sec	$3.240 \times 10^5$			
radians	degrees	57.2958	sq km	acres	247.1004
	min	3437.75		ares	$1 \times 10^4$
	quadrants	0.6366		sq cm	$1 \times 10^{10}$
	sec	$2.0626 \times 10^5$		sq ft	$10.764 \times 10^6$
sec	degrees	$2.778 \times 10^{-4}$	sq links	sq in.	$1.550 \times 10^9$
	min	0.01667		sq m	$1 \times 10^6$
	quadrants	$3.087 \times 10^{-6}$		sq miles	0.3861
	radians	$4.8481 \times 10^{-6}$		sq yd	$1.196 \times 10^6$
Area					
acres	ares	40.46873	sq m	acres	$1 \times 10^{-5}$
	sq chains	10.0		sq chains	$1 \times 10^{-4}$
	sq ft	43,560.0		sq cm	404.69
	ha	0.4047		sq ft	0.4356
	sq link	$1 \times 10^5$		sq in.	62.7264
	sq m	4,046.873		sq m	0.040469
	sq mile	$1.5625 \times 10^{-3}$		sq rods	0.0016
	sq rods	160.0		sq yd	0.0484
	sq yd	4,840.0			
	1	acres		2.471044	sq miles
ares		100.0	ares	0.01	
sq ft		$1.076 \times 10^5$	sq chains	$2.471 \times 10^{-3}$	
sq m		$1 \times 10^4$	sq cm	$1 \times 10^4$	
sq yd		$1.19599 \times 10^4$	ha	$1 \times 10^{-4}$	
			sq ft	10.7639	
			sq in.	1,550.0	
			sq km	$1 \times 10^{-6}$	
			sq links	24.7104	
			sq miles	$3.861 \times 10^{-7}$	
s cm	sq chains	$2.4710 \times 10^{-7}$	sq mm	sq mm	$1 \times 10^6$
	sq ft	$1.076 \times 10^{-3}$		sq rods	0.039537
	sq in.	0.1550		sq yd	1.195985
	sq links	$2.4710 \times 10^{-3}$			
	sq m	0.0001			
	sq miles	$3.861 \times 10^{-11}$			
	sq mm	100.0			
	sq rods	$3.9537 \times 10^{-6}$			
	sq yd	$1.196 \times 10^{-4}$			
	s ft	acres		$2.29568 \times 10^{-5}$	sq rods
ares		$9.29034 \times 10^{-4}$	sq chains	0.0625	
sq chains		$2.29568 \times 10^{-4}$	sq ft	272.25	
sq cm		929.0341			
sq in.		144			
sq links		2.29568			
sq m		0.09290341			

### Area (contd)

To Convert	Into	Multiply by
sq rods (contd)	ha	$2.5293 \times 10^{-3}$
	sq in.	$3.9204 \times 10^4$
	sq links	625.0
	sq m	25.293
	sq miles	$9.7656 \times 10^{-6}$
	sq yd	30.250
sq yd	acres	$2.06612 \times 10^{-4}$
	ares	$8.3613 \times 10^{-3}$
	sq chains	$2.06612 \times 10^{-3}$
	sq cm	8,361.0
	sq ft	9.0
	ha	$8.3613 \times 10^{-5}$
	sq in.	1,296.0
	sq links	20.6612
	sq m	0.83613
	sq miles	$3.2283 \times 10^{-7}$
	sq rods	0.033058
townships	sq km	93.240
	sq miles	36.0
<u>Density</u>		
g/cu cm	lb/cu in.	0.03613
	lb/cu ft	62.43
	lb/gal	8.3452
g/l	lb/1,000 gal	8.345
	lb/cu ft	0.062427
	ppm	1,000.0
kg/cu m	g/cu cm	0.001
	lb/cu ft	0.06243
	lb/cu in.	$3.613 \times 10^{-5}$
mg/l	ppm	1.0
ppm	lb/million gal	8.345
lb/cu ft	g/cu cm	0.01602
	kg/cu m	16.018
	lb/cu in.	$5.787 \times 10^{-4}$
lb/cu in.	g/cu cm	27.680
	kg/cu m	$2.768 \times 10^4$
	lb/cu ft	1728.0
lb/gal	g/cu cm	0.119826

### Flow

acre-ft/day	cu ft/day	43,560.0
	cu ft/sec	0.504
	gal/day	$3.26 \times 10^5$
	gal/min	226.0
	cu m/sec	0.0143
cu ft/day	acre-ft/day	$2.30 \times 10^{-5}$
	cu ft/sec	$1.16 \times 10^{-5}$
	gal/day	7.48
	gal/min	$5.19 \times 10^{-3}$

### Flow (contd)

To Convert	Into	Multiply by
cu ft/day (contd)	cu m/sec	$3.28 \times 10^{-7}$
cu ft/sec	acre-ft/day	1.98
	cu ft/day	86,400
	gal/day	$6.46 \times 10^5$
	gal/min	448.83
	million gal/day	0.646317
	l/min	1,699.3
	cu m/sec	0.0283
	cu yd/min	2.222
gal/day	acre-ft/day	$3.07 \times 10^{-6}$
	cu ft/day	0.134
	cu ft/sec	$1.55 \times 10^{-6}$
	gal/min	$6.94 \times 10^{-4}$
	cu m/sec	$4.38 \times 10^{-8}$
gal/min	acre-ft/day	$4.42 \times 10^{-3}$
	cu ft/day	193.0
	cu ft/hr	8.0208
	cu ft/sec	$2.228 \times 10^{-3}$
	gal/day	1440.0
	l/sec	0.06308
	cu m/sec	$6.308 \times 10^{-5}$
gal/sec	cu ft/min	8.0192
l/min	cu ft/sec	$5.886 \times 10^{-4}$
	gal/sec	$4.403 \times 10^{-3}$
l/sec	cu ft/min	2.12
	gal/min	15.85
cu m/sec	acre-ft/day	70.0
	cu ft/day	$3.05 \times 10^6$
	cu ft/sec	35.3
	gal/day	$2.28 \times 10^7$
	gal/min	15,800
million gal/day	cu ft/sec	1.54723
lb H <sub>2</sub> O/min	cu ft/sec	$2.670 \times 10^{-4}$
tons H <sub>2</sub> O/day	cu ft/hr	1.3349
	gal/min	0.16643
	lb H <sub>2</sub> O/hr	83.333

### Force

dynes	g	$1.0197 \times 10^{-3}$
	joules/cm	$1 \times 10^{-7}$
	kg	$1.0197 \times 10^{-6}$
	newtons	$1 \times 10^{-5}$
g	dynes	980.665
	joules/cm	$9.8066 \times 10^{-5}$
	newtons	$9.086 \times 10^{-3}$
poundals	dynes	13,825.5
	g	14.098

# Force (contd)

To Convert	Into	Multiply by
poundals (contd)	joules/cm	$1.383 \times 10^{-3}$
	newtons	1.383
	lb	0.031081
b	dynes	$4.4482 \times 10^5$
	joules/cm	0.044482
	newtons	4.4482
	poundals	32.174
ewtons	dynes	$1 \times 10^5$
	joules/m	1.0

# Illumination

t-candles	lumens/sq ft	1.0
	lumens/sq m	10.764
	lux	10.764
	milliphot	1.0764
umens/sq ft	ft-candles	1.0
	lumens/sq m	10.764
umens/sq m	ft-candles	0.0929
	lux	1.0
	milliphot	0.1
	phot	$1 \times 10^{-4}$
ix	ft-candles	0.0929
	lumens/sq m	1.0
	milliphot	0.1
	phot	$1 \times 10^{-4}$
lot	ft-candles	929.0
	lumens/sq m	$1 \times 10^4$
	lumens/sq cm	1.0
	lux	$1 \times 10^4$

# Length

Agstrom unit	in.	$3.937 \times 10^{-9}$
	cm	$1 \times 10^{-8}$
	m	$1 \times 10^{-10}$
	microns	$1 \times 10^{-4}$
c	Angstrom units	$1 \times 10^8$
	ft	$3.281 \times 10^{-2}$
	in.	0.39370
	km	$1 \times 10^{-5}$
	m	0.01
	miles	$6.214 \times 10^{-6}$
	mm	10.0
	mils	393.70
	yd	$1.094 \times 10^{-2}$
ains (surveyor's)	chains	
	(engineer's)	0.66
	ft	66.0
	furlong	0.10
	in.	792.0
	links	100
	m	20.117
	miles	0.0125

# Length (contd)

To Convert	Into	Multiply by
chains (surveyor's) (contd)	rods	4.0
	yd	22.0
fathoms	ft	6.0
	m	1.8288
ft	cm	30.4801
	chains	0.01515
	km	$3.048 \times 10^{-4}$
	m	0.3048
	miles (statute)	$1.894 \times 10^{-4}$
	mm	304.8006
	mils	$1.2 \times 10^4$
	rods	0.06061
	yd	0.3333
in.	Angstrom units	$2.540 \times 10^8$
	cm	2.540
	chains	$1.2626 \times 10^{-3}$
	ft	0.08333
	links	0.126263
	m	$2.540 \times 10^{-2}$
	miles	$1.578 \times 10^{-5}$
	mm	25.40
	mils	1,000.0
	rods	$5.05051 \times 10^{-3}$
	yd	$2.778 \times 10^{-2}$
km	cm	$1 \times 10^5$
	ft	3,281.0
	in.	39,370.
	m	1,000.0
	miles	0.6214
	mm	$1 \times 10^6$
	yd	1,093.6
links (surveyor's)	chains	0.01
	cm	20.1168
	ft	0.66
	in.	7.92
	links	
	(engineer's)	0.66
	m	0.201168
	miles	$1.250 \times 10^{-4}$
m	rods	0.04
	yd	0.22
	Angstrom units	$1 \times 10^{10}$
	chains	0.04971
	cm	100.0
	fathoms	0.54681
	ft	3.2808
	in.	39.370
	km	0.001
	links	4.97096
	miles (statute)	$6.219 \times 10^{-4}$
	miles	
	(nautical)	$5.3961 \times 10^{-4}$
	microns	$1 \times 10^6$
	mm	1,000.0

### Length (contd)

To Convert	Into	Multiply by
m (contd)	rods	0.198838
	yd	1.09361
microns	Angstrom units	$1 \times 10^4$
	cm	$1 \times 10^{-4}$
	in.	$3.937 \times 10^{-5}$
	m	$1 \times 10^{-6}$
miles	chains	80.0
(statute)	cm	$1.609 \times 10^5$
	ft	5,280.0
	furlongs	8.0
	in.	$6.3360 \times 10^4$
	km	1.60935
	links	8,000
	m	1,609.35
	miles	
	(nautical)	0.8684
	rods	320.0
	yd	1,760.0
millimicrons	Angstrom units	10.0
	cm	$1 \times 10^{-7}$
	m	$1 \times 10^{-9}$
	microns	0.001
mm	cm	0.1
	ft	$3.281 \times 10^{-3}$
	in.	0.03937
	km	$1 \times 10^{-6}$
	m	0.001
	microns	1,000.0
rods	chains	0.25
	ft	16.50
	furlongs	0.025
	in.	198.0
	links	25.0
	m	5.0292
	miles	$3.125 \times 10^{-3}$
	yd	5.50
yd	chains	0.04545
	cm	91.440
	ft	3.0
	in.	36.0
	km	$9.144 \times 10^{-4}$
	links	4.5454
	m	0.9144
	miles	$5.682 \times 10^{-4}$
	rods	0.1818

### Power

Btu/hr	ft-lb/sec	0.2162
	g-cal/sec	0.0700
	hp-hr	$3.929 \times 10^{-4}$
	watts	0.2931
Btu/min	ft-lb/sec	12.96
	g-cal/min	252.08
	hp	0.02356

### Power (contd)

To Convert	Into	Multiply by
Btu/min (contd)	watts	17.580
ergs/sec	Btu/min	$5.688 \times 10^{-9}$
	dyne-cm/sec	1.0
	ft-lb/min	$4.427 \times 10^{-6}$
	ft-lb/sec	$7.3756 \times 10^{-8}$
	hp	$1.341 \times 10^{-10}$
	kg-cal/min	$1.433 \times 10^{-9}$
	kilowatts	$1 \times 10^{-10}$
	watts	$1 \times 10^{-7}$
ft-lb/min	Btu/min	$1.285 \times 10^{-3}$
	ft-lb/sec	0.01667
	hp	$3.030 \times 10^{-5}$
	kg-cal/min	$3.239 \times 10^{-4}$
	kilowatts	$2.2597 \times 10^{-5}$
	watts	0.022597
ft-lb/sec	Btu/hr	4.6263
	Btu/min	0.077124
	hp	$1.8182 \times 10^{-3}$
	kg-cal/min	0.019433
	kilowatts	$1.356 \times 10^{-3}$
	watts	1.35582
hp	Btu/min	42.418
	Btu/sec	0.70696
	ft-lb/min	$3.30 \times 10^4$
	ft-lb/sec	550.0
	kg-cal/min	10.688
	kilowatts	0.7457
	watts	745.70
watts	Btu/hr	3.4129
	Btu/min	0.05688
	ergs/sec	$1 \times 10^7$
	ft-lb/min	44.254
	ft-lb/sec	0.73756
	hp	$1.341 \times 10^{-3}$
	joules/sec	1.0
	kg-cal/min	0.01433
	kilowatts	0.001
<u>Pressure</u>		
atm	bars	1.0133
	cm Hg (0° C)	76.0
	dynes/sq cm	$1.0325 \times 10^6$
	ft H <sub>2</sub> O (4° C)	33.90
	g/sq cm	1,033.2
	in. Hg (0° C)	29.921
	kg/sq cm	1.0332
	kg/sq m	10,332.0
	mm Hg	760.0
	lb/sq ft	2,116.2
	lb/sq in.	14.696
	tons/sq ft	1.058
	tons/sq in.	0.007348
bars	atm	0.98692
	cm Hg (0° C)	75.006

Pressure (contd)

To Convert	Into	Multiply by
bars (contd)	dynes/sq cm	$1 \times 10^6$
	ft H <sub>2</sub> O (4° C)	33.456
	in. Hg (0° C)	29.5296
	kg/sq m	10,197
	lb/sq in.	14.5038
	lb/sq ft	2,082.0
cm Hg (0° C)	atm	0.013158
	bars	$1.33322 \times 10^{-2}$
	dynes/sq cm	$1.33322 \times 10^4$
	ft H <sub>2</sub> O	0.4461
	kg/sq m	135.95
	lb/sq ft	27.85
	lb/sq in.	0.1934
dyne/sq cm	atm	$9.8692 \times 10^{-7}$
	bars	$1 \times 10^{-6}$
	cm H <sub>2</sub> O (4° C)	$1.01974 \times 10^{-3}$
	g/sq cm	$1.01971 \times 10^{-3}$
	in. H <sub>2</sub> O (4° C)	$4.0148 \times 10^{-4}$
	in. Hg (0° C)	$2.9530 \times 10^{-5}$
	kg/sq m	$1.01971 \times 10^{-2}$
	lb/sq ft	$2.0886 \times 10^{-3}$
	lb/sq in.	$1.4504 \times 10^{-5}$
	mm Hg (0° C)	$7.5006 \times 10^{-4}$
ft H <sub>2</sub> O (4° C)	atm	0.02950
	in. Hg (0° C)	0.8826
	kg/sq cm	0.03048
	kg/sq m	304.8006
	lb/sq ft	62.426
	lb/sq in.	0.43352
g/sq cm	atm	$9.6784 \times 10^{-4}$
	dynes/sq cm	980.665
	kg/sq m	10.0
	lb/sq ft	2.0481
	lb/sq in.	0.014223
	mm Hg (0° C)	0.73556
in. Hg (0° C)	atm	0.03342
	dynes/sq cm	$3.3864 \times 10^4$
	ft H <sub>2</sub> O (4° C)	1.1329
	kg/sq cm	0.03453
	kg/sq m	345.31
	lb/sq ft	70.73
	lb/sq in.	0.4912
in. H <sub>2</sub> O (4° C)	atm	$2.458 \times 10^{-3}$
	dynes/sq cm	2,490.82
	in. Hg (0° C)	0.07355
	kg/sq cm	$2.540 \times 10^{-3}$
	oz/sq in.	0.5781
	lb/sq ft	5.204
	lb/sq in.	0.03613
g/sq cm	atm	0.9678
	dynes/sq cm	$9.8067 \times 10^5$
	cm Hg (0° C)	73.556
	ft H <sub>2</sub> O (4° C)	32.81
	in. Hg (0° C)	28.96
	lb/sq ft	2,048.1

Pressure (contd)

To Convert	Into	Multiply by
kg/sq cm (contd)	lb/sq in.	14.223
kg/sq m	atm	$9.678 \times 10^{-5}$
	bars	$98.07 \times 10^{-6}$
	dynes/sq cm	98.0665
	ft H <sub>2</sub> O (4° C)	$3.281 \times 10^{-3}$
	g/sq cm	0.10
	in. Hg (0° C)	$2.896 \times 10^{-3}$
	mm Hg (0° C)	0.073556
	lb/sq ft	0.2048
	lb/sq in.	$1.422 \times 10^{-3}$
oz/sq in.	dynes/sq cm	4,309.2
	lb/sq in.	0.0625
lb/sq ft	atm	$4.725 \times 10^{-4}$
	bars	$4.7880 \times 10^{-4}$
	dynes/sq cm	478.80
	ft H <sub>2</sub> O (4° C)	0.01602
	g/sq cm	0.48824
	in. Hg (0° C)	0.01414
	kg/sq m	4.8824
	mm Hg (0° C)	0.35913
	lb/sq in.	$6.944 \times 10^{-3}$
lb/sq in.	atm	0.06804
	bars	0.068947
	cm Hg (0° C)	5.1715
	dynes/sq cm	$6.8947 \times 10^4$
	ft H <sub>2</sub> O (4° C)	2.3066
	g/sq cm	70.307
	in. Hg (0° C)	2.0360
	kg/sq m	703.07
	lb/sq ft	144.0
<u>Time</u>		
days	hr	24.0
(mean solar)	min	1,440.0
	sec	86,400.0
hr (mean solar)	days	$4.167 \times 10^{-2}$
	min	60.0
	sec	3,600.0
	weeks	$5.952 \times 10^{-3}$
min (time)	day	$6.9445 \times 10^{-4}$
	hr	0.01666
	sec	60.0
	weeks	$9.9206 \times 10^{-5}$
months (mean)	days	30.42
	hr	730.0
	min	$4.380 \times 10^4$
	sec	$2.628 \times 10^6$
weeks	hr	168.0
	min	$1.0080 \times 10^4$
	sec	$6.0480 \times 10^5$

Velocity		
To Convert	Into	Multiply by
cm/sec	ft/min	1.9685
	ft/sec	0.03281
	km/hr	0.0360
	knots	0.01944
	m/min	0.60
	miles/hr	0.02237
	miles/min	$3.728 \times 10^{-4}$
ft/min	cm/sec	0.5080
	ft/sec	0.01667
	km/hr	0.01829
	knots	0.009868
	m/min	0.3048
	m/sec	0.005080
	miles/hr	0.01136
ft/sec	cm/sec	30.480
	km/hr	1.0973
	knots	0.5921
	m/min	18.29
	miles/hr	0.6818
	miles/min	0.01136
km/hr	cm/sec	27.778
	ft/min	54.68
	ft/sec	0.9113
	km/min	0.01667
	knots	0.5396
	m/min	16.667
	m/sec	0.2778
	miles/hr	0.6214
	cm/sec	51.48
	ft/hr	6,080.0
knots	ft/min	101.337
	ft/sec	1.689
	km/hr	1.8532
	m/sec	0.51479
	miles	
	(nautical)/hr	1.0
	miles	
	(statute)/hr	1.1516
	cm/sec	1.6667
	ft/min	3.281
m/min	ft/sec	0.05468
	km/hr	0.060
	knots	0.03238
	miles/hr	0.03728
	cm/sec	100.0
	ft/min	196.8
m/sec	ft/sec	3.281
	km/hr	3.60
	km/min	0.060
	knots	1.9425
	miles/hr	2.2369
	miles/min	0.03728
	cm/sec	44.704
	ft/min	88.0
miles/hr	ft/sec	1.4667

Velocity (contd)		
To Convert	Into	Multiply by
miles/hr (contd)	km/hr	1.609
	km/min	0.02682
	knots	0.8684
	m/min	26.82
miles/min	miles/min	0.01667
	cm/sec	2,682.2
	ft/sec	88.0
	km/min	1.609
	knots	52.104
	knots/min	0.8684
acre-ft	miles/hr	60.0
	Volume	
	cu ft	43,560.0
	gal	$3.259 \times 10^5$
	cu in.	$7.53 \times 10^7$
	cu m	1,233.49
	bd ft	2,359.8
	cu ft	0.08333
	cu in.	144.0
	cu m	$2.3598 \times 10^{-3}$
cords	cord ft	8.0
	cu ft	128.0
	cu m	3.625
cord ft	cords	0.125
	cu ft	16.0
cu cm	bd ft	$4.2376 \times 10^{-4}$
	cu ft	$3.53144 \times 10^{-5}$
	gal (US fluid)	$2.642 \times 10^{-4}$
	cu in.	0.06102
	l	0.001
	cu m	$1 \times 10^{-6}$
	cu mm	1,000.0
	oz (US fluid)	0.033814
	pt (US fluid)	$2.1134 \times 10^{-3}$
	qt (US fluid)	$1.0567 \times 10^{-3}$
	cu yd	$1.3079 \times 10^{-6}$
cu ft	bd ft	12.0
	cords	0.0078125
	cord ft	0.0625
	cu cm	28,320.0
	gal (US fluid)	7.48052
	cu in.	1,728.0
	l	28.316
	cu m	0.028317
	pt (US fluid)	59.844
	qt (US fluid)	29.922
cu in.	cu yd	0.03704
	bd ft	$6.944 \times 10^{-3}$
	cu cm	16.38716
	cu ft	$5.7870 \times 10^{-4}$
	gal (US fluid)	$4.3290 \times 10^{-3}$
	l	$1.6387 \times 10^{-2}$
	cu m	$1.6387 \times 10^{-5}$

# Volume (Contd)

To Convert	Into	Multiply by
cu in. (contd)	cu mm	$1.6387 \times 10^4$
	oz (US fluid)	0.5541
	pt (US fluid)	$3.463 \times 10^{-2}$
	qt (US fluid)	$1.732 \times 10^{-2}$
	cu yd	$2.14335 \times 10^{-5}$
cu m	bd ft	423.76
	cords	0.2759
	cu cm	$1 \times 10^6$
	cu ft	35.3144
	cu in.	$6.1023 \times 10^4$
	l	1,000.0
	cu mm	$1 \times 10^9$
	pt (US fluid)	2,113.4
	qt (US fluid)	1,056.7
	cu yd	1.3079
cu yd	cu ft	27.0
	gal (US fluid)	202.0
	cu in.	46,656.0
	l	764.54
	cu m	0.764559
	pt (US fluid)	1,616.0
	qt (US fluid)	807.9
gal	cu cm	3,785.4
	cu ft	0.13368
	cu in.	231.0
	l	3.785
	cu m	$3.785 \times 10^{-3}$
	oz (US fluid)	128.0
	pt (US fluid)	8.0
	qt (US fluid)	4
	cu yd	$4.951 \times 10^{-3}$
l	cu cm	1,000.0
	cu ft	0.03531
	gal (US fluid)	0.2642
	cu in.	61.02
	cu m	0.001
	oz (US fluid)	33.8147
	pt (US fluid)	2.113
	qt (US fluid)	1.057
	cu yd	$1.308 \times 10^{-3}$
microliters	l	$1 \times 10^{-6}$
ml	l	0.001
oz (US fluid)	cu cm	29.5737
	cu in.	1.80469
	l	0.02957
	pt (US fluid)	0.06250
pt (US fluid)	cu cm	473.179
	cu ft	0.01671
	gal	0.125
	cu in.	28.875
	l	0.4732
	cu m	$4.732 \times 10^{-4}$
	oz (US fluid)	16.0
	qt (US fluid)	0.50

# Volume (Contd)

To Convert	Into	Multiply by
qt (US fluid)	cu cm	946.358
	cu ft	0.03342
	gal (US fluid)	0.25
	cu in.	57.749
	l	0.94633
	cu m	$9.4633 \times 10^{-4}$
	pt (US fluid)	2.0
Weight		
gal H <sub>2</sub> O (4° C)	kg H <sub>2</sub> O	3.78533
	lb H <sub>2</sub> O	8.34522
g	kg	0.001
	mg	1,000.0
	oz (avoirdupois)	0.03527
	oz (troy)	0.03215
kg	lb	$2.205 \times 10^{-3}$
	g	1,000.0
	oz (avoirdupois)	35.2739
	oz (troy)	32.1507
	lb (avoirdupois)	2.2046
	tons (long)	$9.842 \times 10^{-4}$
	tons (short)	$1.102 \times 10^{-3}$
	g	$1 \times 10^{-8}$
	g	0.001
oz (avoirdupois)	g	28.3495
	oz (troy)	0.91146
	lb	0.06250
lb (avoirdupois)	grains	7,000.0
	g	453.5924
	kg	0.4536
	oz (avoirdupois)	16.0
	oz (troy)	14.5833
	lb (troy)	1.2153
	tons (long)	$4.4643 \times 10^{-4}$
lb H <sub>2</sub> O	tons (short)	$5.0 \times 10^{-4}$
	cu in.	27.68
	cu ft	0.01602
tons (long)	gal	0.1198
	kg	1,016.047
	lb	2,240.0
	tons (metric)	1.01605
tons (short)	tons (short)	1.1200
	kg	907.1848
	lb	2,000.0
	tons (long)	0.89287
	tons (metric)	0.9071848

Work; energy		
To Convert	Into	Multiply by
Btu	ergs	$1.0548 \times 10^{10}$
	ft-lb	777.97
	g-cal	251.98
	hp-hr	$3.9292 \times 10^{-4}$
	joules	1,054.8
	kg-cal	0.25198
	kilowatt-hr	$2.928 \times 10^{-4}$
ergs	Btu	$9.4805 \times 10^{-11}$
	dyne-cm	1.0
	ft-lb	$7.3756 \times 10^{-8}$
	ft-poundals	$2.3730 \times 10^{-6}$
	g-cal	$2.3889 \times 10^{-8}$
	g-cm	$1.020 \times 10^{-3}$
	joules	$1 \times 10^{-7}$
	kg-cal	$2.3889 \times 10^{-11}$
	kg-m	$1.020 \times 10^{-8}$
	kilowatt-hr	$2.778 \times 10^{-14}$
	watt-hr	$2.778 \times 10^{-11}$
ft-lb	Btu	$1.286 \times 10^{-3}$
	ergs	$1.356 \times 10^7$
	ft-poundals	32.174
	g-cal	0.32389
	hp-hr	$5.050 \times 10^{-7}$
	joules	1.35582
	kg-cal	$3.239 \times 10^{-4}$
	kg-m	0.1383
	kilowatt-hr	$3.766 \times 10^{-7}$
g-cal (mean)	Btu	$3.9685 \times 10^{-3}$
	ergs	$4.1868 \times 10^7$
	ft-lb	3.0874
	ft-poundals	99.334
	hp-hr	$1.5593 \times 10^{-6}$
	joules	4.186
	kg-cal	0.001
	kg-m	0.42685
	kilowatt-hr	$1.1628 \times 10^{-6}$
	watt-hr	$1.1628 \times 10^{-3}$

Work; energy (contd)		
To Convert	Into	Multiply by
kg-cal (mean)	g-cal (mean)	1,000.0
g-cm	Btu	$9.297 \times 10^{-8}$
	ergs	980.7
	ft-lb	$7.233 \times 10^{-5}$
	g-cal	$2.3427 \times 10^{-5}$
	joules	$9.807 \times 10^{-5}$
	kg-cal	$2.343 \times 10^{-8}$
	kg-m	$1 \times 10^{-5}$
hp-hr	Btu	2,545.0
	ergs	$2.6845 \times 10^{13}$
	ft-lb	$1.980 \times 10^6$
	g-cal	$6.41190 \times 10^5$
	joules	$2.684 \times 10^6$
	kg-cal	641.30
	kg-m	$2.737 \times 10^5$
	kilowatt-hr	0.7457
joules	Btu	$9.480 \times 10^{-4}$
	ergs	$1 \times 10^7$
joules (contd)	ft-lb	0.7376
	g-cal	0.23889
	g-cm	$1.0197 \times 10^4$
	hp-hr	$3.725 \times 10^{-7}$
	kg-cal	$2.3889 \times 10^{-4}$
	kg-m	0.1020
	watt-hr	$2.778 \times 10^{-4}$
watt-hr	Btu	3.4130
	ergs	$3.60 \times 10^{10}$
	ft-lb	2,655.3
	g-cal	860.01
	hp-hr	$1.341 \times 10^{-3}$
	joules	3,600.0
	kg-cal	0.86001
	kg-m	367.10
	kilowatt-hr	0.001

# CONVERSION TABLES

Table 10.--Conversion of temperature from Fahrenheit to Centigrade

(In °C)

°F	0	1	2	3	4	5	6	7	8	9
-30	-34.44	-35.00	-35.56	-36.11	-36.67	-37.22	-37.78	-38.33	-38.89	-39.44
-20	-28.89	-29.44	-30.00	-30.56	-31.11	-31.67	-32.22	-32.78	-33.33	-33.89
-10	-23.33	-23.89	-24.44	-25.00	-25.56	-26.11	-26.67	-27.22	-27.78	-28.33
0	-17.78	-18.33	-18.89	-19.44	-20.00	-20.56	-21.11	-21.67	-22.22	-22.78
+0	-17.78	-17.22	-16.67	-16.11	-15.56	-15.00	-14.44	-13.89	-13.33	-12.78
10	-12.22	-11.67	-11.11	-10.56	-10.00	-9.44	-8.89	-8.33	-7.78	-7.22
20	-6.67	-6.11	-5.56	-5.00	-4.44	-3.89	-3.33	-2.78	-2.22	-1.67
30	-1.11	-0.56	0.00	0.56	1.11	1.67	2.22	2.78	3.33	3.89
40	4.44	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.44
50	10.00	10.56	11.11	11.67	12.22	12.78	13.33	13.89	14.44	15.00
60	15.56	16.11	16.67	17.22	17.78	18.33	18.89	19.44	20.00	20.56
70	21.11	21.67	22.22	22.78	23.33	23.89	24.44	25.00	25.56	26.11
80	26.67	27.22	27.78	28.33	28.89	29.44	30.00	30.56	31.11	31.67
90	32.22	32.78	33.33	33.89	34.44	35.00	35.56	36.11	36.67	37.22
100	37.78	38.33	38.89	39.44	40.00	40.56	41.11	41.67	42.22	42.78

Table 11.--Conversion of temperature from Centigrade to Fahrenheit

(In °F)

°C	0	1	2	3	4	5	6	7	8	9
-30	-22.00	-23.80	-25.60	-27.40	-29.20	-31.00	-32.80	-34.60	-36.40	-38.20
-20	-4.00	-5.80	-7.60	-9.40	-11.20	-13.00	-14.80	-16.60	-18.40	-20.20
-10	14.00	12.20	10.40	8.60	6.80	5.00	3.20	1.40	-0.40	-2.20
0	32.00	30.20	28.40	26.60	24.80	23.00	21.20	19.40	17.60	15.80
+0	32.00	33.80	35.60	37.40	39.20	41.00	42.80	44.60	46.40	48.20
10	50.00	51.80	53.60	55.40	57.20	59.00	60.80	62.60	64.40	66.20
20	68.00	69.80	71.60	73.40	75.20	77.00	78.80	80.60	82.40	84.20
30	86.00	87.80	89.60	91.40	93.20	95.00	96.80	98.60	100.40	102.20
40	104.00	105.80	107.60	109.40	111.20	113.00	114.80	116.60	118.40	120.20

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# OUTDOOR RECREATION RESEARCH: APPLYING the RESULTS

PAPERS FROM  
A WORKSHOP  
HELD BY THE

USDA FOREST SERVICE AT  
MARQUETTE, MICHIGAN,  
JUNE 19-21, 1973.

NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

North Central Forest Experiment Station  
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(Maintained in cooperation with the University of Minnesota)

## FOREWORD

These collected papers were the basis for discussions at a Recreation Research Applications Workshop held at Marquette, Michigan, in June 1973. The Workshop was designed to bring together Forest Service recreation researchers from throughout the country and forest recreation planners and managers from the north-central States for the purpose of exchanging information, ideas, and problems, and encouraging the application of research findings by practitioners.

A key part of the Workshop was of course the discussion among the 80 some persons who attended. But the papers themselves, state-of-the-science summaries prepared in advance by experts in various fields, contain valuable information worthy of much wider dissemination.

Recreation research is rather new for Forest Service scientists and for their colleagues in other public and private organizations. There is a need for all researchers to work closely with land managers. The Marquette Workshop was one effort to promote this interaction. We hope these papers will be useful to the many interested people who could not attend.

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# A REVIEW OF RECREATION LAND ALLOCATION ON THE MARK TWAIN NATIONAL FOREST

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**ABSTRACT.**--This paper discusses conflicts between recreation users and competition for land and facilities on the Mark Twain National Forest. Relevant literature was reviewed for applicability. Past and current allocations for recreation on the Mark Twain National Forest were reviewed and the results, if known, reported. Conclusions are offered for thought.

## THE USERS

Most problems of land allocation for recreation use are the result of conflict between the types of users and the land they utilize. A short discussion of the type of user, his impact, and conflicts is in order.

Motorcyclists come in two main categories: (a) the people (or families) who ride trail bikes within campgrounds; and (b) those who ride in the general forest zone. The campground rider is very much in conflict with other campers in the area, primarily because of bike noise and the safety hazard involved in heavy utilization of the roads. The trail rider in the general forest zone is often in conflict with the land itself, causing erosion, and with other users who don't appreciate the noise or the use of the bikes.

Most cyclists feel that they have a right to be on the forest. They often cannot understand how they are in conflict with other users (how other people don't appreciate the sound or the use of the bikes in their area). Motorcyclists are gregarious, often organized into clubs; and prefer to ride in groups. The sport requires a substantial land base in order to get the length of trails or enough space for open riding. Most cyclists prefer to ride unencumbered by rules and regulations. They would rather have the

challenge of a forest without trails than have the Forest Service construct trails for their use. Their need for esthetic surroundings is low. Unfortunately, indiscriminate trails are hazardous to the land. Because of the nature of conflict between the motorcyclist and almost every other forest user, he finds himself in the minority position when it comes to allocating land uses. This becomes a major problem because of the amount of acreage needed for the motorcyclist.

Dune buggies create many of the same problems posed by motorcycles. They need more room to operate and as a result often use creek beds and water courses, thus causing erosion.

The horseback rider's space requirements are very similar to those of the motorcyclist. A horseman requires room for trails, cross-country riding, and for loading and unloading. The erosion hazard from horses is not as great as from motorcycles. A properly constructed horse trail does not have an adverse impact on the environment. Horses are in conflict with some hikers who do not appreciate dung piles in the trail and horses near their primitive camp areas. The equestrian does not sit easily if he must be alert to cycles that may spook his or other horses.

The average day hiker normally requires, or prefers, a trail, although cross-country challenges are growing in

popularity. The length of the trail desired varies as to his purpose. The backpacker is more or less self-contained, carrying his own food and equipment. The length of trail required for a backpacker should be considerably longer than for the day hiker. The backpacker requires a place to camp. If backpackers pick the same campsite continuously, there is a sanitation problem. Sanitation facilities in remote areas are expensive to build and difficult to maintain. Backpackers are best characterized by their desire to get away from the sound and the rush of the daily world. Most man-made sounds are objectionable to them. The hiker and the backpacker require space, much as the horseback rider and the motorcyclist. The hiker's and backpacker's need for esthetic surroundings is high.

River floaters who prefer the non-motorized experience of a canoe or john-boat desire solitude and quiet, though they are also gregarious and prefer to make trips in groups. Most floaters don't seem to object to groups of their own kind. However, they resent groups of other kinds, including hikers. Floaters can present sanitation problems, particularly if they camp overnight.

Substantial Federal ownership or esthetic control is desirable along good float streams. Ownership currently presents a more serious problem for floaters than for the backpacker or the cyclist because most riverbanks are in private ownership which hinders access to streams and leads to unesthetic development on their margins.

The floater is also in conflict with the bank fisherman or the boat fisherman or the motorboater.

The use of motors on rivers has several adverse effects: the noise, wave action eroding the bank, the oil film left on the water, the safety hazard to other boats, and bank fishermen being disturbed by the motorboat.

Fishermen fall primarily into two groups, boat fishermen and bank fishermen. The boat fisherman often has the same impact as the powerboater. Fishermen generally prefer their section of the river to be their own so they have less competition. They generally resent intru-

sion by other users. The biggest problem presented by boat fishermen is the litter left in the streams. Bank fishermen create other problems, though normally they are confined to areas near where they can park their cars. They create trails along the stream, wear down the bank at places where they fish, and are responsible for most of the bank's litter. Most bank fishermen resent boats crossing their lines or otherwise disturbing their immediate fishing area. Most fishermen, whether bank or boat fishing, prefer access close to where the fishing is. The use of automobiles in stream bottoms is always a risky proposition. The roads they create are susceptible to erosion damage during times of floods. Auto access also means that more litter can be carried in.

The water skier requires large acreages of water in which to ski. The only area on the Mark Twain available for this is Table Rock Lake. He causes no problem to other water users until he approaches the bank. Then he interferes with the fishermen along the bank. The noise of the ski boat is often distracting to other users. The ski boat by its size requires a launching lane into the water. The ramp and the associated parking lot can take up a substantial area.

Swimmers look for clear, clean water in a safe environment. They do not want to be threatened by ski boats, other motorboats or fishermen. Oil from two-cycle engines leaves an unpleasant film on the water. Swimmers normally prefer to park close to the swimming area. They want a clean environment to change clothes. They need a safe, clean walk from the parking lot or bathhouse to the beach. The swimming area should be carefully graded and marked with buoys. The construction of a bathhouse near the water always presents waste disposal problems.

Hunting, by the nature of the sport, requires a substantial area. Many hunters seem to want to drive into the location where they are going to hunt, yet have the area to themselves. The hunter does not normally care to hunt in areas where other people are. This scares his game and reduces his chance of a kill. Nothing would irritate a hunter more than to have a deer in his rifle sights and have the animal scared off by a motorcyclist or other user.

Hikers and others avoid woods during big game season out of fear of being shot. On extended squirrel, deer, or turkey hunting trips, hunters will often set up a camp. Where hunting camps have been established through the years, trees have been cut for firewood, and camp furniture, tent poles, and litter remain. Hunters sometimes cause forest fires by setting fires in den trees to smoke out squirrels.

Most people who go to the forest to observe wildlife seek a degree of quiet and solitude. Any other interference is an intrusion on their activity. It is hard to accommodate these people specifically, unless there are placed like heron rookeries, beaver dams, or other predictable habitations.

People who drive or ride for pleasure are concerned primarily with the beauty of the forest and the road on which they are riding. The pleasure driver would prefer to be on a road with little traffic, low speed, and preferably without many obstructions. The pleasure rider would prefer not to see many of the harsh practices involved in forest land management.

Picnickers usually seek a pleasant spot in which to have their lunch. This does not necessarily have to be a developed site. They would prefer to drive close to the place where they will eat. Three hundred feet is about the maximum distance anyone will carry a picnic basket. They prefer a table, a fireplace or charcoal grill in the shade. They desire shelters during inclement weather. Some of the problems involved are sanitation, littering, and auto access. Drinking water is desirable. Open areas for games such as horsehoes and softball are desirable.

Auto camper desires vary from isolation to crowds; from primitive to motel-type accommodations. Equipment varies from the primitive essentials to self-contained units. Auto campers need a place to park and sanitation. In a National Forest this means roads for access, a spur on which to park, tent space, a garbage receptacle, and toilet. Drinking water is optional. Roads, spurs, and spacing require room. Sanitation becomes more complex as size increases. Pollution standards become tighter as proximity to water increases.

Auto campsites are more costly and complex to maintain and rehabilitate. Self-contained units are causing problems such as dumping holding tanks and draining sinks. Transistorized radio-TV's are noise polluters. In addition, campers want activities such as fishing, swimming or hiking near the campground.

"Pot hunter" is the term used to describe people who comb the National Forests for historical and prehistorical artifacts for fun and profit. This is an illegal act that is difficult to control. This type of collector is particularly harmful because he destroys knowledge as well as beauty or material value.

Vandalism, a common but unappreciated use, takes many forms. It ranges from tearing down notices on a bulletin board to burning down a building. These acts are encouraged by isolated sites and sparse administration which creates the opportunity to vandalize unobserved. Vandalism is usually the result of, or the aftermath of, a late night party when judgments are impaired by alcohol or drugs. Vandalism extends beyond the developed sites to include the wanton destruction of caves or other natural features.

## OUR DILEMMA

Historically, we have looked to development as a means of accommodating forest users. By concentrating on development, we have, in the past, alienated most people seeking dispersed recreation. These people came to the forest anyway. When their numbers increased to where an impact or conflict was being felt, the forest was not prepared, through staffing, attitudes, and policies, to cope with the situation. Conversely, we have seldom tied developed sites in with good dispersed-use opportunities as skillfully as we could. Thus we found ourselves with developed, but unused sites, because once there the camper had nothing to do.

Legislation, national policies, and recognition of trends have brought about change. The gap between wilderness and auto campgrounds is wide, diverse, and competitive. This competition is best displayed through the current forms of legislation proposed to designate land for one purpose or another.

The Forest Service has found its vast acreages shrinking rapidly. The unit of measure is in the mind. What was once thought of as timber producing or grazing land is now being considered for many other purposes. The many publics and interests want their fair share.

Today's manager often finds that he must be the judge of what a fair share is on his land unit. This judgment is often made with insufficient evidence.

There are no hard answers to most management allocation problems. Just as there are several options within the recreation function, there are many more options in other functions--all for the same acre of land. There are decisions made daily which may affect a piece of landscape for a century. A manager must know what areas to dedicate to long-term use without sacrificing too many options. There are various methods of collecting, storing, and processing data. There are also various methods of using data to arrive at decisions. None of the methods will yield a perfect answer because there is none.

It is in vogue to speak of mixes. What is the right management mix? Again, there is no perfect mix. A plan decided on today is obsolete tomorrow. The changes are brought about by competition for the land to yield different goods and services. There is also a strong competition for the time of forest personnel. Land use allocations are affected strongly by assignment of personnel. The most competitive people will present the stronger case. This must be recognized as a part of land management.

## THE LITERATURE

Available recreation research literature for the last 10 years was reviewed for this project. It was screened for content as it applied to land use allocations. There are studies which apply to parts of demand, user preferences, and methods of recreation land allocations. Most studies, by necessity, are based on strict geographic limits.

This presents a problem in managing National Forests in the Ozark Region. User preferences, habits, and use patterns vary considerably on Districts within the

Mark Twain National Forest. These differences should be reflected throughout National Forests and Districts in the Ozark Region. In the final analysis, the managers and planners must rely on past use trends, inventories, projections, and judgment to allocate land for specific uses. We can find no research conducted in the Ozark Region for any form of recreation use. We conclude that research is needed on a regional basis to provide more applicable guides to administration.

## Management Allocations in Practice

We've coped, and are coping, with a few allocation problems on the Mark Twain and thought we would share them with you.

Demand figures, which directly affect planning and allocation, have been inadequate. There is hope on the horizon from current studies that will improve this situation. There is a general problem in many demand data.

For example, the State Recreation Plan for Missouri draws general conclusions which are not applicable to National Forest use. The category "camping" ranges from highly developed organization camps to undeveloped sites. The National forests meet a small portion of this demand and then only that of those campers interested in a specific type of environment.

On Table Rock Lake there are family campgrounds provided by private enterprise, the State of Missouri, the Corps of Engineers, and the Forest Service. All have different philosophies of management, design, and construction. All are experiencing a capacity use by people seeking the experience level they prefer. Statistically, these sites are lumped under the general category of camping, yet there are in reality five different activities. Saturation of one category could negate construction of another type of campground which is badly needed. Data by use category must be expanded before it is realistic.

We are currently constructing hiking trails in response to an apparent demand by conservation clubs, scouts, and individuals. These trails are being used, but it is too early to say if they will be used enough to be called successful.

The Chadwick area of the Ava District has a long established use of several hundred motorcycle riders per weekend during cool weather. The riders had established a trail system of sorts and several hill climbs. Erosion was becoming severe. Riders were turning to other places on the forest, endangering more fragile landscapes. The forest is attempting to control this use by: (1) constructing a 50-mile trail system to Forest Service standards, (2) initiating rules and regulations to prohibit off-trail use, (3) closing the remainder of the forest to off-road use by motorized vehicles.

Motorboating on small lakes, under 50 acres, is not allowed on the Mark Twain because of the lack of space, water pollution, noise and bank erosion. A substantial boat landing is needed to launch a motorboat, more so than for carry-in nonpower craft.

The majority of lands within the Eleven Point National Scenic River are zoned for experience level two. We have planned two activities within the zone which are within this experience level. The zone will be accessible by nonpower boat and by foot. Float camps are generally separated from hiking camps. Hikers using float camps during the floating season could exceed the carrying capacity of the campsite. Through trail layout, design and information, we will discourage hikers from using most float camps. Although the seasons for hiking and floating are different, each is extending, and overlap is likely. The peak use for boating occurs during the hot summer months. For hiking it is spring and fall. Until spring and fall floating use becomes heavier, the float camps could accommodate some hikers.

The use of motors on johnboats on the Eleven Point River is being discouraged and may eventually be restricted by regulation. An exception to this is being made to accommodate the gigger during the fall gigging season. This sport is traditionally conducted at night with lights and occurs in late fall. Allocation in this activity is within a time frame.

Seasons and time of day have a direct relationship in allocating activity opportunities. A classic example is the use of motorcycles and nature study. In

Missouri, summer temperatures are too high for the air-cooled trail bikes. The trails vacated by motorcycles during the summer months could be used by nature hikers. This allows activities that would normally be in conflict to occur on the same area.

A campground was constructed adjacent to U.S. 60, a major east-west arterial carrying up to 5,000 cars daily. Highway traffic studies indicated 10 percent plus was cross-country vacation traffic. After 3 years of operation, the primary use of this site occurs late in the evening after a local drive-in movie closes. Legitimate campers would account for less than 5 percent of the total use. The site was probably developed before sufficient study was completed.

A well-planned study does not always have the final answer. A ranger on the Van Buren District sent an inquiry to most of the listed saddle clubs in the State of Missouri. The response favorable to a cross-country trail was overwhelming. On the strength of this response, 15 miles of horse trail, a corral-picnic ground, and two ponds were constructed. A brochure was prepared to inform trail riders of these facilities. Over an 8-year period, actual use has been confined to one annual organized trail ride and sporadic small group use. We had a very similar experience within 40 miles of Springfield where there are over 3,000 horses stabled. In the Springfield case, the public demanded, the Forest Service responded, but the use did not materialize.

Carman Springs is a cooperative game refuge with the State of Missouri on the National Forest. The original purpose of stocking game animals and birds has about lost its significance. Should the area be opened to hunting like the rest of the forest or is this an opportunity to provide a refuge for nonhunters who would enjoy an outing during hunting seasons and a special use for the nonconsumptive wildlife user?

## CONCLUSIONS

Private enterprise, organizations, State, county, and city facilities are

answering an obvious need. The National Forests meet yet another need. The land base and physical opportunities on the National Forest are staggering. It would be easy to get carried away with grandiose plans for golf courses and swimming pools. We must recognize that our greatest potential for the recreating public is the opportunity to provide solitude and elbow room. Our emphasis in allocations must reflect this need.

The actual acreage needed for meeting demands of occupancy-type recreation is insignificant to the whole on the National Forests. The problem is which acreage to occupy. Historically, camp and picnic grounds have been constructed on the prime lands adjacent to water. There is not much prime land available for further development. There is also a trend of reserving the prime lands for esthetic and ecological reasons. This trend places potential development sites in areas less desirable to the camper but more compatible to the overall picture.

Day-use activities such as picnicking can serve more people because of higher densities and turnover. A picnic site then would have a higher priority

for prime lands if the demand was great enough.

Boating sites obviously must be near water. The selection of the boating site often dictates the design of a site because of the complexities of a launching ramp or carry-in lane. This is especially true of rivers that habitually have floods with high velocities.

Very few sites will meet all the criteria for a good swimming area. This places swimming in first priority for site selection.

Allocation priorities on multi-activity development sites become: (1) swimming, (2) boating, (3) picnicking, and (4) camping, assuming demand is relatively equal.

The factors of land capability, interest group pressures, present commitment, political pressure, and current policies must be welded into a decision for the allocation of land uses. We must recognize that these decisions are based on current, available information and circumstances. We must retain a degree of flexibility to change priorities and allocations. One real skill of land use allocation is to retain room for options.

# ECONOMIC BASES FOR ALLOCATING RESOURCES

## IN OUTDOOR RECREATION

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**ABSTRACT.**--A review of the literature on economics as it relates to outdoor recreation suggests that the concept of supply and demand forces interacting in the market is a helpful way to look at the outdoor recreation problem. However, it is not clear how best to determine supply and demand in practice. The peak-load demand problem is characteristic of outdoor recreation. Differential pricing is suggested to redistribute use from peak to off-peak use periods. The cost of producing a user unit of activity (for example, a group-night of camping) is suggested as a guide to deciding whether or not new investment in facilities is justified.

### THE PROBLEM

Forest land managers provide facilities and services that people want and need for outdoor recreation. Facilities may be as simple and primitive as a trail, or a two-rut road with few parking areas, or as elaborate as an intensively developed campground with an all-weather surfaced highway. The land itself, with its plant and animal life, can also be thought of as a recreational facility. Services may range from interpreting the natural ecosystem to picking up the garbage.

Providing facilities and services takes land, men, materials, and money. Typically, some or all of these are scarce resources to managers. Seldom are there enough resources to do all the jobs that could be done. Thus, the manager must decide the number and kinds of facilities and services, and where and when to provide them, to meet the varied and often conflicting outdoor recreation needs of people. He also must decide whether to charge for these facilities and services, and if so, how much and when.

Here economics may be able to help. Economics studies the allocation of scarce resources for producing goods and services to meet people's needs. It considers both private and public institutions and organizations created to produce and distribute these goods and services. Economics not only describes how things are, but suggests how efficient and equitable things should be (Scitovsky 1971, p. 5). It has developed a framework and tools for analyzing resource allocation problems that may be helpful in recreation.

### DEMAND AND SUPPLY IN THE MARKET

One of the most helpful contributions of economics has been the concept of the market, in which the opposing forces of demand and supply interact to eventually establish a balance between price and quantity exchanged (Johnson 1968). A market can be defined for each good or service for a given time period and place. One of the distinguishing features of such a market is the idea that the amount that sellers are willing to sell and the amount buyers are willing to buy varies with the market price--in other words, there exist alternative levels of quantities demanded and quantities supplied. The economist attempts to develop demand and supply curves or functions by relating quantity to price (Milstein 1961). He assumes that once these have been determined, producers can use them in planning how much to produce and what price to charge.

Much traditional economic theory was developed to explain the pure competitive market in which many willing buyers and sellers, who individually have no influence on the market price and who have complete information and freedom to enter or leave the market, buy and sell identical products (Naylor and Vernon 1969, p. 43). In such a market the equilibrium price ( $P_e$ ) is established by the intersection of the supply and demand curves (fig. 1). At this price the amount sellers are willing to supply just equals the amount buyers demand ( $Q_e$ ), and a market equilibrium is reached. The competitive market, through the price mechanism, automatically allocates resources efficiently, giving rise

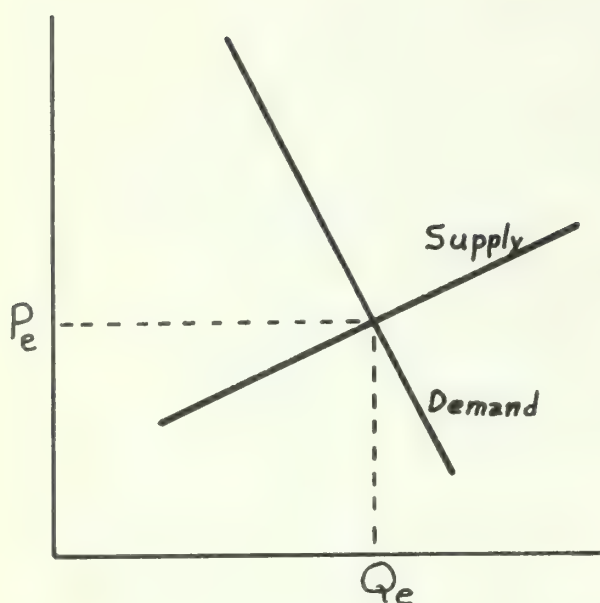


Figure 1.--The equilibrium price ( $P_e$ ) and quantity ( $Q_e$ ) are established in a competitive market by the intersection of the supply and demand curves.

to the idea of the market as the "invisible hand" that guides resource allocation.

Unfortunately, this ideal, pure, competitive market bears little resemblance to actual market conditions for outdoor recreation, where quantities and prices of unique recreation facilities typically are set by a few suppliers on a take-it-or-leave-it basis. Despite this, most economic theory applied to outdoor recreation problems has relied strongly on the pure competitive model, even though it may not be strictly applicable.

Obviously, if we are to study the allocation by the market of scarce resources to produce the outdoor recreation facilities and services people want, we have a two-part problem on our hands. First, we must know what facilities and services people want, how much, where and when. This is the demand part of the problem. Second, we must know what resources are available and what facilities and services can be provided by various means, how much, where, and when. This is the supply part.

In applying the economic concepts of supply and demand to outdoor recreation, some confusion has arisen because at times

no distinction was made between the term "demand" and the terms "use" or "consumption." Supply and demand functions are schedules of alternative levels of production or consumption at various prices. Use or consumption estimates are single points reflecting the amount actually exchanged at the price established in the market.

Participation rates or past use has been used widely to project future "demand" for recreation. Typically, these rates are related to user or population characteristics such as income, age, or occupation. Unfortunately, the participation rates reported for recreation are not determined solely by demand factors such as distance traveled, education, and income, but also by the supply of recreation facilities available (Seneca and Cicchetti 1969). Use of participation rates to establish supply and demand curves gives rise to the "identification problem" in econometrics--the inability to identify whether changes in participation are due to changes in supply, or demand, or both (Cicchetti, Seneca, and Davidson 1969, Cicchetti *et al.* 1972). But many of these details are of a more technical nature, of interest primarily to an economist, and we will say no more about them. They do, however, affect the validity and believability of efforts to determine supply and demand.

Outdoor recreation facilities and services have, in the past, been provided by public agencies free of charge or at fixed prices administratively determined. Seldom, if ever, has the quantity provided or the price charged reflected either the cost of production or the willingness and ability of users to pay, as would be expected in market-priced goods. Without a market-established price as a guide, public land and managers and administrators have difficulty determining how much should be provided to allocate resources efficiently. With escalating costs and more careful scrutiny of budgets by legislators and others, administrators feel compelled to find methods for justifying expenditures on recreation facilities.

In the absence of a market price, economists have sought other ways of establishing a price or value of recreation. Trice and Wood (1958) used travel costs to a recreation site as the basis for estimating the value of a visitor-day, coming up with about \$2 per day. Wennergren (1964)

argued that, "Cost expenditures can be used to establish value for a commodity that lacks conventional market pricing." He suggested that the "price" for boating should include the travel costs to and from the boating site plus the onsite expenditures for an individual user. Wennergren and others suggest valuing the resource on the idea of consumer surplus, the amount consumers would be willing to pay for a good or service over the amount they actually have to pay to get it.<sup>1</sup>

Many economists do not accept consumer surplus as a satisfactory measure of recreation value for comparison with other goods (Beazley 1961, Norton 1970, Beardsley 1971). They argue correctly that consumer surplus values should not be compared to market-price values, since these values are different. Market-price value corresponds to the old concept of value in exchange, while consumer surplus corresponds to value in use less the market-price value.<sup>2</sup>

Attempts have been made to establish demand curves by the direct method of asking users how much camping they would do at various fee levels (LaPage 1968). Fisher and Krutilla (1972) suggest this approach. This approach, of course, suffers from the uncertainty in relating what people say they would do with what, in fact, they will do, and from possible intentional biases in responses (Knetsch and Davis 1966).

One difficulty in trying to determine supply-demand curves for a particular recreation activity or site is the complex joint nature of recreation activities. Clawson and Knetsch (1963) identify five phases of the recreation experience: planning or anticipation, travel to the site, onsite experiences, travel back, and recollection. Each of these phases has its own costs and benefits (economic and social), occurring at different times, and it is necessary to consider the total cost of the whole experience in quantifying demand functions (Kalter and Gosse 1970). Also, any one activity may be part

<sup>1</sup>Net consumer surplus is typically taken to be the area under the demand curve but above the market price (Wennergren 1964).

<sup>2</sup>For a brief discussion of consumer surplus see p. 436-437 in Samuelson (1973). For a detailed analysis of the concept see Currie, Murphy, and Schmitz (1971).

of a complex of activities forming a trip package. The demand for any one given site is strongly influenced by the supply of other recreation facilities and opportunities available, and often these change considerably over time (Clawson and Knetsch 1966). Then, too, the demand may be affected greatly by the quality of the site, and this in turn may be affected by the level of use and by size and scale of operations (Robinson 1967). All of this greatly complicates the job of deriving demand functions for a particular site, activity, and time.

A survey of the literature on the economics of outdoor recreation provides no clear idea of how to go about using the market approach to allocate resources. I can only agree with Beazley (1961), who over a decade ago concluded, "Presently we cannot measure consistently *any* values or benefits in an ultimate, comparable sense." Nevertheless, the basic concept of the market, that there exist alternative levels of supply and demand, and that both interact to determine the "best" level of production and consumption, is helpful in studying outdoor recreation (Castle and Stoevener 1970, Clawson and Knetsch 1963, Kalter and Gosse 1970).

#### SPECIAL CHARACTERISTICS OF RECREATION DEMAND

Anyone studying outdoor recreation immediately recognizes the wide range of people's needs and preferences for facilities and services (Hendee 1969, Hendee, Gale, and Catton 1971). Even for an activity such as camping the range is wide (King 1968, Lucas 1964, Merriam *et al.* 1973, Lucas 1970, Shafer 1969, Wagar 1963, West, McCool, and Merriam 1969). It is obvious that public agencies must recognize this diversity and provide a wide range of recreational opportunities (Goldin 1972, Krutilla 1967, U.S. Congress 1970). To meet user's needs we must better understand why people go where they do (Lime 1972). We must recognize that consumer's preferences and choices are affected by what is available--they can use only what is provided (Ciriacy-Wantrup 1963). Also, the quality of the recreation site, its location, design, and size affect the demand for the facilities. Thus, supply and demand are tightly woven to form the fabric of recreation activities.

But for outdoor recreation planning it is not enough to know the general level of demand. We also must recognize that user's time preferences vary widely and that users are constrained by weather, the school year, traditional work hours and work weeks, holidays, and other social and institutional forces in scheduling recreation activities. Because of this, much outdoor recreation use exhibits peaked-demand characteristics (Beazley 1961, James 1970, Goldin 1972). Many campgrounds filled to overflowing on a summer holiday weekend may be only 20 percent occupied during the weekday. Because outdoor recreation is strongly time-oriented, a campsite on a Wednesday in August is not equivalent to the same campsite on July 4th. The seasonal nature of many activities is evident (cross-country skiing, snowshoeing, water-skiing, sailing, canoeing), especially in northern areas. Hunting and fishing seasons are limited by law and so become highly time-oriented. Watching for migratory birds, driving to view fall colors, gathering certain mushrooms and berries, and many other recreation activities are typically concentrated into a short period, thus contributing to a peak-load demand for some facilities and services.

Variations in demand over time create problems in defining capacity and in designing facilities to meet demands. Do you design camping facilities to meet the average daily camping load, the average weekday camping load, the weekend peak load, or to meet the summer holiday weekend peak load? Can you design an element of flexible capacity into recreation facilities to meet peak-load demand? The answers to these questions depend in part on the time pattern of use for an individual facility. It may also depend on the cost of providing these facilities and services. Economics can provide information that may help decide these questions, and we will discuss only this aspect of the topic.

If an increase in the general level of demand for camping is expected, the part of this increase that occurs during off-peak periods when the campground is not fully used can be met, up to the capacity of the campground, at little extra cost. Only the demand in excess of existing capacity should be considered in planning for new facilities.

#### PRODUCTION COST AS AN ALLOCATION TOOL

One economic guide that may be helpful to the recreation manager in planning rec-

reational facilities to meet anticipated demand is the production cost per unit of output. Knowing what it costs to provide a group-night of camping, a ski-touring trip, or a boat launching under different conditions may help the manager decide whether or not he can justify providing the facilities.

The annual cost of providing a user facility--say a campsite--can be determined by using standard investment analysis procedures. As an example, suppose the construction cost of a modern campsite in a national forest in the Lake States was \$3,000, the annual maintenance was \$50, and the reconstruction cost was estimated to be \$1,000 every 20 years.<sup>3</sup> With a 5-percent discount rate, the annual cost (AC) of providing this site would be:

$$AC = 0.05(\$3,000 + \frac{\$50}{.05} + \$1,000 \left( \frac{1}{(1.05)^{20} - 1} \right))$$

$$AC = 0.05(\$3,000 + \$1,000 + \$600)$$

$$= \$230 \text{ per site per year}$$

With this information, together with expected annual use, one can estimate the cost of providing a group-night of camping. If annual occupancy is expected to be 100 group-nights, then the average cost of providing the campsite would be \$2.30 per group-night. If the campsite will be used only 10 nights a year to meet peak demand on summer holidays, then the average cost is \$23 per group-night. Obviously, the level of expected use can have a major impact on the anticipated cost of providing the facility. Lime (1971), in a study of campgrounds on the Superior National Forest, found a wide variation in use of individual campsites within campgrounds, including some campsites that had seldom if ever been used, and among campgrounds as a whole. If the campsite in our example were used only 1 night a year, whether through poor design, location, or excess capacity in the campground, the \$230 it would cost to provide a group-night of camping would be hard to justify on any economic grounds.

This average cost information is useful in planning new facilities, but it has little relation to the cost of making the facility available to the user once it is

<sup>3</sup>These figures are my educated guesses and are probably low. Nevertheless, they seem reasonable enough as a basis for discussion.

built. The added or marginal cost of providing a group-night of camping in a campground that is not full may be essentially zero, except for the added cost of services and wear on the site. On the other hand, as the example above showed, constructing new facilities to handle excess demand that occurs only on summer holiday weekends could cost \$20 or more per group-night of camping. This analysis doesn't tell us whether or not to construct new facilities to meet increased demand, but it may help us to understand how much it costs to meet different kinds of demand and to decide on a reasonable level of facilities based on expected use. Providing recreation facilities can be expensive, and managers should be aware of the cost of doing so, particularly if the expected use is light. Satisfying expressed needs and wants may be a noble goal, but price must be considered.

Our economic formulation of the campsite problem tells us that the cost per group-night can be lowered if the number of group-nights per year can be increased, but it also tells us that the group-night cost can be reduced by reducing construction and operations costs. Where use is light or only occasional, primarily during holidays or a few special days, perhaps the peak-load demand can be handled by cheaper, portable facilities, reduced facilities (unfurnished expansion camping areas), or temporary undeveloped camping areas, all of which might be considerably less costly to provide. This is, in fact, what managers sometimes do, with good economic justification.

This same general approach can be applied to a wide range of recreation facilities, including picnic areas, boat launching ramps, cross-country ski trails, and others. Knowing what it costs to provide the facilities and services for one unit of recreation experience (a group picnic, a boat launching, a cross-country ski tour, etc.) does not give a complete economic basis for allocating resources, but it can help the manager decide what level of facilities and services to provide.

#### PRICE AS AN ALLOCATION TOOL

Because prices for outdoor recreation facilities and services are controllable by the public agencies, price can be used as a tool to re-allocate use, at least to some extent. Goldin (1972), for example, suggests charging market clearing prices for each type of facility and each demand period. Some of the experience with handling

peak loads in the public utilities industry may be of help here.<sup>4</sup> Regarding the electrical utility industry, De Salvia (1969) concludes that "peak-load pricing based on economic principles offers a practical solution to the problem of supplying peak loads." He argues that charging higher prices during peak-load periods and lower prices during off-peak periods would tend to depress peak demands and stimulate off-peak consumption.

In such a time-dependent activity as outdoor recreation, differential pricing might have a relatively small effect in distributing use over time. Nevertheless, it should be considered seriously as a potential management tool (Lime and Stankey 1971). Redistribution of use from peak-load to under-capacity use periods in effect provides new facilities by making use of unused facilities. Beazley (1961) and others have pointed out how effective recreation capacity could be increased by changing society's customs in the use of time, substituting Mondays for Saturdays as the "day off" for half the work force, rescheduling vacations, and so on. Although these actions are beyond the direct control of the outdoor recreation manager, they do emphasize an important principle. More outdoor recreation capacity can be provided not only by constructing new facilities, but also by making more effective use of existing facilities where they are now underutilized. From society's viewpoint, that may be the most efficient way of providing for some of the anticipated increased recreation demand.

#### A SUMMARY

In the time allotted we have only been able to consider briefly two aspects of economics as it relates to outdoor recreation. We have seen that the concept of supply and demand forces interacting in the market is a helpful way to look at the outdoor recreation problem, although it is not clear just how best to determine supply and demand in practice. We also have looked at the peak-load demand problem, characteristic of outdoor recreation. We proposed using cost of producing a user unit of activity (a group-night of camping, for example) as a guide to deciding whether new in-

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<sup>4</sup>For examples of a more comprehensive discussion of peak-load analysis see Brown and Johnson (1969) and Williamson (1966).

vestment in facilities is justified or not, and suggested differential pricing to redistribute use from peak-use to off-peak use periods.

Time did not permit us to explore these subjects in any detail. Those interested can consult the references cited as a starting point. Neither were we able to investigate one important aspect of economics--the distribution of costs and benefits, the who-pays and who-gets part of economics. The literature relating to economic aspects of outdoor recreation is expanding rapidly.

I hope to have conveyed the impression that a considerable amount of work has been done on providing economic bases for resources allocation in outdoor recreation, even though it is still too early to see clearly how effective much of it has been. Although much remains to be done, the work done to date should demonstrate that economic concepts do provide a helpful way to view allocation problems in recreation, and some may provide a guide to management decisions.

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## SOCIAL CARRYING CAPACITY FOR BACKCOUNTRY RECREATION

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**ABSTRACT.**--Carrying capacity in wildland recreation areas is a complex concept that relates to many aspects of use in addition to numbers of users. Management objectives are essential to provide standards against which changes caused by use can be judged as acceptable or unacceptable. Visitors' attitudes are a second essential factor in setting carrying capacities. Impacts of use on physical-biological resources are the third important influence on capacities. Social carrying capacity is considered in relation to "backcountry", defined as roadless recreation areas, but not classified Wilderness. Growing use, decreasing opportunities, and the lack of a comprehensive management program contribute to the problem of social carrying capacity. Social carrying capacity research to date is reviewed. It shows that solitude is a major attraction and influences satisfaction. Campsite privacy is particularly important. Mechanized recreationists value solitude less and detract from the experience of nonmechanized visitors. This is the major use conflict. Most visitors do not desire much in the way of facilities. Research results suggest environmental management in backcountry, especially for fish and wildlife, could be intensive. Projections point to rapid future growth in backcountry use. A more positive management program appears necessary to meet this growing pressure.

### THE CARRYING CAPACITY CONCEPT

There is widespread and intense concern that many wildland recreation areas are threatened by overuse. One solution--establishing carrying capacities for specific areas--at first glance seems easy to do but upon close examination becomes extremely difficult (Wagar 1964). As Lime and Stankey (1971) point out, recreational carrying capacity is not a value easily arrived at. For a particular recreation area there is no magic number that "is the carrying capacity."

In fields such as range management, carrying capacity can be described in a relatively straightforward fashion. For that reason, some have suggested that the term "carrying capacity" is inappropriate in recreation management. However, the rationale for applying the carrying capacity concept to recreation is that (1) recreation provides a particular service to people; (2) the service (or the product of the recreation resource) is a result of the interaction between the individual, other users, and the resource; and (3) beyond certain limits, this product is adversely affected by excessive congestion, resource deterioration, or both. Finally, although the term "car-

rying capacity" may not be the best for the recreation context, it has been used so much that coining a new term seems unwise.

In defining recreational carrying capacity, we assume the goal of recreation management is to maximize user satisfaction. Within constraints--administrative and policy considerations, budgets, and resource capability--managers try to define the kind and amount of use an area can support over a specified time without causing an unacceptable change in either the physical environment or the recreational experience.

The crucial part of this process, of course, is deciding what constitutes "unacceptable" (or acceptable) change (Frissell and Stankey 1972). The answer lies in three interrelated determinants of carrying capacity: (1) management objectives; (2) visitor attitudes; and (3) impacts on physical resources. No single factor sets capacity; all are important, but their relative significance varies from one opportunity to another.

### MANAGEMENT OBJECTIVES

Capacity can be judged only against the management objectives for a specific area--objectives that define the recrea-

tional opportunity (or opportunities) the area is intended to provide.

A variety of opportunities is needed, but this does not mean each manager must try to provide an endless variety of different types of areas. Burch (1964) pointed out that although a wide range of recreational tastes exists, certain activities tend to go with one another. These "activity aggregates" impose certain demands on the resource and have certain effects on other uses. Regionwide planning is needed to meet the diversity of recreational tastes. However, "no one recreation supplier need feel obligated to meet all demands. Each public agency could aim clearly at a part of the demand, and refer people who want something more, less, or different to a more appropriate area" (Lucas 1963b). This requires coordination, as well as informing the public who is providing what and where.

Management objectives are standards against which managers judge whether or not use is consistent with an area's carrying capacity. If objectives change because of agency policy, public pressure, or other reasons, so does the definition of what is appropriate and what is not. In the absence of clear objectives, however, attempts to make consistent and defensible judgments about capacity will be futile.

### VISITOR ATTITUDES

All recreationists do not perceive the environment in the same way; what is a quality recreational experience to one may be unsatisfactory to another. What the recreationist perceives as acceptable or desirable also may be quite different from what the manager perceives and from what the manager *thinks* the public perceives (Stone and Taves 1958, Lucas 1964b, Hendee and Harris 1970). In a study of National Forest campgrounds, Lucas (1970) found visitors ranked recreational site quality very differently (usually higher) than did Forest Service administrators.

Defining recreation standards and objectives involves *values*. Whose values are to count most--the managing agency's or the public's? If public values are to be relied upon, which "public"?

It is impossible to please everyone everywhere, and some attitudes *are* more relevant than others. "It seems misleading to give equal weight to evaluations by people who are seeking a different type of area or experience" (Lucas 1970). If

we provide a full range of opportunities (regardless of the agency or organization that provides them), we can match visitor needs with opportunities rather than try to develop recreation areas for the mythical "average user" (Shafer 1969, Wagar 1966); a process that could gradually dissatisfy almost everyone.

Although management cannot base decisions solely on public opinion, visitor attitudes are a good indication of how well management objectives match user objectives. From this, we can define the spectrum and the mix of opportunities needed. Furthermore, attitudes also indicate how visitors might respond to specific management actions. Knowing who may dislike a given management action and explaining why their preferences cannot be met can be as important as deciding for whom the area will be managed (Lime 1972). Surveys of public attitudes can give objective, unbiased feedback to the manager. A manager confronted by a few complaints may overreact if he has no way of tapping the opinions of the majority who usually come and go quietly.

### IMPACT ON PHYSICAL-BIOLOGICAL RESOURCES

How much wear and tear of the resources should the manager permit before he says, "that's enough"? Recreational impact on physical-biological resources is the third component of carrying capacity.

Any use of an ecosystem results in some change; Frissell and Duncan (1965) found that only light use of camping sites in the Boundary Waters Canoe Area (BWCA) removed over 80 percent of the ground cover. Even in locations managed to maintain a natural or near-natural setting, we must accept less than total achievement of the goal if we allow any use at all.

The manager must know (1) what change will occur under specific levels and types of use, and (2) how the change relates to the management objectives for the area, taking into account how people perceive and respond to changes in the physical environment (here, social and ecological aspects mesh because both help to define unacceptable changes). If the predicted change is inconsistent with objectives, the manager has three options: (1) ignore the problem and take no action; (2) change the management objectives (e.g., from low-density to high-density recreation); (3) prevent predicted change, through design, restrictions, or facilities.

The manager takes action based on how a change relates to management objectives, rather than directly on the change itself. In a developed, high-density-use campground, the manager could use many techniques to counter resource damage; for example, paving, or planting hardy species. However, at a hike-in campsite where the objective is to provide a camping opportunity in a fairly natural setting, and where the amount of resource change permissible would be comparatively small, the manager probably would have to rely more on use restrictions (numbers of people, kind of use) rather than on techniques that "harden" the site.

### THE BACKCOUNTRY CONCEPT

We use the term "backcountry" to refer to any area where the management objectives stress dispersed, off-road recreation activities: hiking, cross-country skiing, snowshoeing, snowmobiling, trail bike riding, canoeing, boating, river floating, horseback riding, hunting, fishing, bird watching, camping, and others. We consider backcountry a recreation area, in contrast to Wilderness, which we define as primarily a large natural ecosystem, to be experienced as it is. By definition, recreational opportunities could be enhanced or even created in backcountry, but not in Wilderness. Educational opportunities could also be expanded in backcountry, through roving naturalists, interpretive signing, trailside exhibits, and so on.

If one pictures a spectrum of recreation opportunities (Lloyd and Fischer 1972) ranging from highly developed to undeveloped (fig. 1), backcountry spans a range of opportunities from wilderness to, perhaps, areas accessible by jeep.

Most backcountry should be relatively natural but not to the extent of wilderness. The degree of naturalness would depend on where an area's objectives fall on the spectrum. Intensity of recreation would be light, but generally would not provide the solitude offered by wilderness.

In the midwestern United States and the Great Lakes region of Canada, several recreation areas would meet our definition of backcountry (not wilderness), at least in part, to name a few: Algonquin Provincial Park, Ontario; Porcupine Mountains State Park, Michigan; Sylvania Recreation Area, Ottawa National Forest; Namakagon River, Wisconsin; and the Pine River, Michigan. Additional examples from other parts of the country could be cited, such as the Jewel Basin Hiking Area, Flathead National Forest, Montana.

### THE PROBLEM

Three factors contribute to the problem of social carrying capacity for backcountry--soaring use, decreasing opportunities, and the lack of a comprehensive management program.

### Use--Substantial and Growing Fast

Interest and participation in primitive recreational experiences has been booming. Although we are concerned here with a wider range of activities, wilderness use is one index of this boom. Between 1950 and 1970, reported visits to the National Forest Wilderness and primitive areas increased ninefold, while nonwilderness recreation tripled. In recent years, about one-fourth of the reported National Forest recreation visitor-days were spent on trails and "general undeveloped areas," including

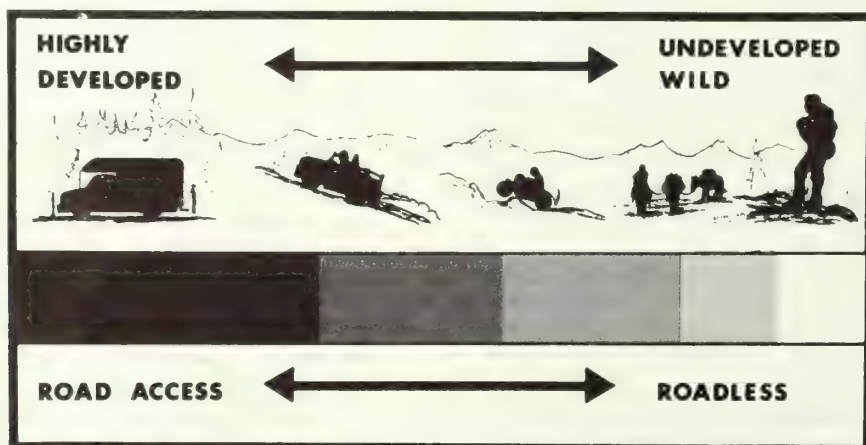


Figure 1.--The recreation opportunity spectrum.

Wilderness (although the greatest part of of the use is outside Wilderness). Another 12 or 13 percent were spent on lakes and streams, some of which would be backcountry as we have defined it. Again, use statistics show high rates of growth. Recently, dispersed mechanized recreation (snowmobiles and trail bikes, mainly) has exploded (Lucas 1971).

#### Opportunities--Limited and Declining

Outside established special areas, undeveloped lands are scarce, especially in the Midwestern and Eastern United States, and almost surely declining as roads and other developments break the remnants into ever smaller and less significant pieces. Outdoor Recreation Resources Review Commission (ORRRC) Report 8 (1962b) showed 98 percent of sample air photo points in the Northeastern United States were within one-half mile of a road--and that was over a decade ago! Private land, especially shorelines, that once provided much backcountry recreation is being developed at a fast pace (Borchert *et al.* 1970). Trail systems are being gradually whittled away by roads and trail abandonment, and new trail construction has not kept pace (Lucas 1971).

Backcountry recreation calls for low-intensity use and a degree of solitude. Thus, growing use on a dwindling land base will lower the quality of the experience. This is already a problem many places, as indicated by complaints about streams overloaded with canoes, overflowing trail shelters, and so on. Furthermore, the boom in both mechanized transportation (trail bikes, snowmobiles), and more primitive transportation (backpacking, horses) intensifies conflicts and poses severe problems in social carrying capacity.

#### Management Programs--Limited and Stalled

A comprehensive program for a system of backcountry recreation areas does not exist. There are scattered, individual examples--and we named a few--however, most opportunities are on lands unmanaged or, at best, minimally managed for backcountry or dispersed recreation. These are mainly leftover lands, and informal backcountry use is unplanned for, not really an objective for the area. The lack of objectives and the absence of management programs intensify and accelerate the loss of opportunities for back-

country recreation. Intensified management could probably raise the recreational capacity of backcountry areas appreciably. However, to do this, we need a much better grasp of the social aspects of carrying capacity.

#### WHAT IS KNOWN ABOUT SOCIAL CARRYING CAPACITY?

Research dealing specifically with backcountry, especially in the Midwest, is limited. There have been studies of visitors in Algonquin Provincial Park,<sup>1</sup> the Adirondacks (Shafer and Mietz 1969), Michigan's Pine River (Solomon and Hansen 1972), and some other backcountry areas. In addition, a few studies discuss recreational activities like snowmobiling that could be important in backcountry. Although few of these studies were focused on carrying capacity, some of their results are pertinent.

The recent annotated bibliography on carrying capacity by George Stankey and Dave Lime (1973) lists over 200 publications; about 50 pertain to what they call "esthetic carrying capacity" and 60 more relate to "managing for carrying capacity."

Most of our knowledge of backcountry carrying capacity must be borrowed or adapted from studies of Wilderness visitors. Social carrying capacity has been studied in depth, particularly in the BWCA of the Superior National Forest (Lucas 1963a, 1964a, 1964b, 1964c, 1965; Lime 1972; Stankey 1971, 1972, 1973), Adjacent Quetico Provincial Park in Ontario has been studied also (Lusty 1968). This research has considerable transfer value for understanding backcountry social carrying capacity.

Mountainous terrain and greater use of horses may make it difficult to adapt western Wilderness studies (Hendee *et al.* 1968, Merriam 1963, ORRRC 1962a, and research in progress by Lucas and Stankey) to the Midwest. One study that includes the BWCA and three western areas (Stankey 1971) concluded that although differences among individual areas would always have to be weighed when prescribing guidelines for carrying capacity, there are, never-

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<sup>1</sup> George E. Priddle. *Wilderness perception in the Algonquin Park interior*. Unpubl. M.S. thesis, Clark Univ. Grad. Sch. of Geogr., Worcester, Mass. 1964.

theless, certain broad, generic appeals about wilderness that appear unaffected by particular area characteristics. For instance, the idea that wilderness should offer an opportunity for solitude is accepted regardless of the levels of use, resource variability, or proximity to population centers. On the other hand, certain unique characteristics, such as a predominance of horse use, do give rise to differing ideas as to what is appropriate or desirable use.

### Type of Experience Sought

The type of recreation experience sought has some important aspects: levels of use or solitude desired, conflicts among various recreation activities, compatibility with commodity production, specific activities desired, importance of area size, and need for overnight as compared to day-use opportunities.

#### Solitude

Studies of Wilderness and backcountry show most visitors want solitude and that past some unspecified threshold of use, satisfaction declines.

Social carrying capacity has been studied mostly in Wilderness. In the Boundary Waters Canoe Area, Lucas (1964a) found canoeists objected to encountering other visitors more than did motorboaters and motor canoeists. Canoeists defined crowding not only in numbers of people, but also in types of use (specifically disliking motorboats). On lakes where total season use was less than 300 groups of canoeists, most canoeists felt that crowding had not destroyed the wilderness experience. Where motorboats were found, however, canoeists felt crowded at a much lower level of use. In his study in the BWCA and three western Wildernesses, Stankey (1971) found tolerance to crowding was a function not only of the level and type of use encountered, but also of where and when the encounters took place, and the behavior of visitors. Campsite privacy was more important than encounters while traveling. Most visitors wanted to camp out of sight and sound of other parties, but most reported their satisfaction did not drop substantially until they met more than about two or three parties a day while traveling. Littering was disliked even more intensely than crowding.

On the heavily used Pine River in Michigan--about 1,000 canoeists on a typi-

cal Saturday or Sunday--about one-fifth of the visitors still gave "solitude" as a reason for their trip (Solomon and Hansen 1972). Again, "littering" was the most common complaint and "too many people" rated second. Complaints about crowding came almost entirely on weekends when use was heaviest. Quetico Provincial Park visitors also complained most about littering, and next most often about visitors using outboard motors--general crowding was third (Lusty 1968). One-third of the visitors said they sometimes felt crowded and were bothered by more than two parties on the same lake, full campsites, and motorboats. Again, campsite privacy was important--85 percent wanted to camp away from all other visitors.

Algonquin Provincial Park canoeists rated a lack of people the second most important attraction; fishermen rated it sixth. The canoeists' main reason for preferring Algonquin to other areas was "lack of people" (Priddle *et al.*, n.d.) Again, most Algonquin visitors wanted to camp out of sight of other parties.

A study of Adirondack hikers did not ask directly about solitude, but we can infer its importance from the fact hikers rated "social motivations" last as a reason for hiking (Shafer and Mietz 1969).

Mechanized recreationists are much less concerned with solitude and tolerate or enjoy heavier use than nonmechanized visitors (Lucas 1964a, 1964b; Lusty 1968; Stankey 1971; Lucas, study in progress). They are more interested in fishing than the nonmechanized users (Lusty 1968, Lucas 1965). Unpublished data from visitor surveys in Montana and Idaho (Lucas) also suggest more emphasis on hunting and fishing in backcountry, than in Wilderness, but this was most true in an area where airplane access was common, and this mechanized access may be the main explanation, rather than the fact the areas were backcountry.

In summary, solitude is an important value for nonmechanized users of backcountry, but the level of solitude desired for particular types of backcountry areas must be determined through future experience and research. For the wilderness-like areas, we do know that isolated campsites are generally best, rather than sites clustered in campground-type designs. Daily encounters with other parties while traveling in backcountry should probably not exceed two or three per day at the wilderness end of

the spectrum and range upward for areas toward the developed end of the spectrum. How high this level of use might be cannot be determined from present knowledge.

#### Use Conflicts

The major conflict is between the mechanized and nonmechanized recreationists. Most of the nonmechanized visitors have a strong aversion to mechanized use. Studies of reactions to motorboats and trail bikes (Lucas 1964a, 1964b; Hendee *et al.* 1968; Stankey 1971; Lucas, research in progress) uniformly show this aversion. Conflicts between snowmobile operators and cross-country skiers and snowshoers are also intense.<sup>2</sup> It is a one-way conflict; the mechanized users do not dislike the nonmechanized users.

To us, the conflict seems severe enough that areas open to mechanized, dispersed recreation must be recognized as unsuitable for nonmechanized uses; trying to combine both appears unlikely to succeed. Zoning separate areas for each use seems logical, especially because of the different visitor motivations mentioned before (e.g., mechanized visitors are more interested in fishing), the lower importance mechanized visitors attach to solitude, and their greater acceptance of heavy use.

There are also serious conflicts involving large parties--smaller groups of visitors strongly dislike large groups (Stankey 1971).

Horsemen and hikers conflict, but to a much lesser degree than mechanized and nonmechanized visitors. Most hikers feel horse travel *is* appropriate in Wilderness; however, most of them prefer meeting other hikers and some of them are bothered by the physical damage horses cause on trails and at campsites (Stankey 1973).

#### Compatibility with Commodity Uses

There is little data on this issue. Canoeists on the Pine River did not complain about a dam they had to portage around (Solomon and Hansen 1972). Visitors to Quetico Provincial Park (Lusty 1968), the Boundary Waters Canoe Area (Lucas 1963a), and Algonquin Provincial

Park<sup>1</sup> (Lucas and Priddle 1964) generally did not notice the carefully controlled logging in these areas. When they did, about 50 percent complained. However, the *idea* of logging in backcountry seems even more objectionable than the reality; when asked, most visitors reject the practice (ORRRC 1962a).

#### Types of Activities Desired

Studies suggest that in backcountry a diverse mix of activities is important, but that fishing, and perhaps hunting, are key values, more so than in Wilderness. This is especially true for mechanized recreationists and much less true for river canoeists and floaters--only 4 percent of the Pine River canoeists fished (Solomon and Hansen 1972). The opportunity for off-road travel itself is the other key value. Swimming, camping, nature study, and so on can all be important.

#### Area Size

Size of backcountry areas can be highly variable; in some cases they might be quite small (Hutchison 1962). The studies cited indicate that as size increases, lengths of stay also increase, and more visitors come from outside the local area--probably indicating the area has greater perceived significance. Total capacity also increases as size increases, of course, although probably at a declining rate (a curvilinear relationship between size and capacity) because much use is brief and marginal, and fringe areas are usually crowded before the core is fully used. This is not necessarily inefficient; in fact, it provides greater diversity of experience and can be very desirable.

One would think mechanized recreationists would require a larger area because such rapid transportation consumes space faster than nonmechanized means of transportation. This may be true for snowmobiles<sup>2</sup> and perhaps trail bikes--we are unaware of any relevant data on trail bikes--but motorboats and motorized canoes actually penetrate *less* deeply into the BWCA and Quetico Provincial Park than paddlers at a time when no zones were closed to motorized use (Lucas 1964c). This is probably because those in motorboats were mainly interested in fishing; the canoeists wanted a broader, more diverse experience.

<sup>2</sup> William Brown Mahoney. *Winter recreation conflicts in two areas near Missoula, Montana*. Unpubl. M.S. thesis, Univ. Montana, Missoula. 1973.

## Day Use vs. Overnight Use

Day use of backcountry areas is very common, especially on the smaller areas. About 60 percent of the Pine River canoeists were day-users (Solomon and Hansen 1972). Over half of the visitors were day-users in four Montana Wildernesses and backcountry areas smaller than 100,000 acres (Lucas, study in progress). Even the Selway-Bitterroot, largest Wilderness in the Nation, has almost as many day-users as overnight users, although the three other large areas studied had from only 14 to 40 percent day-use.

Mechanized use runs heavily to day-use. In the BWCA, Lime and Buchman (1973) report day-users made up 95 percent of snowmobilers, 65 percent of motorboaters, 37 percent of motor canoeists, but only 23 percent of paddling canoeists. Limited unpublished data (Lucas, study in progress) indicate trail bike riders also are overwhelmingly day-users.

Visitors to Wilderness and backcountry areas reveal mixed attitudes toward level of development, management practices, and use regulations. This emphasizes the need for diversity, which could be furthered by backcountry areas to supplement Wilderness and by diversity within and between backcountry areas.

## Level of Development

Different factors relate to social carrying capacity for day-users and overnight campers. Campers prefer campsite seclusion and not meeting too many other parties traveling. We believe day-users will accept less solitude and tolerate heavier use than overnight visitors. If this proves true, then overnight campers become the group to consider when establishing social carrying capacity for any area with significant overnight use.

## Management Preferences

Most Wilderness visitors studied favor little or no development--fireplaces, tables, and high-standard trails are all opposed by more than support them (Hendee *et al.* 1968; Stankey 1973; Lusty 1968; Lucas, study in progress). The study by Hendee showed more visitors favored outhouses than opposed them; in other studies (in different areas) the reverse was true. Most users favored bridges, especially across large streams. Although the general preference in all areas studied is towards relatively undeveloped conditions, all studies show

substantial minorities who *do* prefer more development. This is especially true of the mechanized travelers. Bridges and outhouses are the most desired and least objectionable developments. Loose rock fireplaces on which visitors can place their own grill seem preferable to cemented iron grates. In most places tables are an unnecessary expense. Where they are provided, split log tables are highly preferred to plank construction.

Generally, facilities should be developed with restraint, only where a clear need exists, and not just for the sake of building something.

## Environmental Manipulation

Backcountry opens up exciting possibilities for enhancing recreation opportunities in ways ruled out in Wilderness. The importance of water for fishing, scenic beauty, and campsite settings suggests that small, earthen dams to create natural-appearing ponds and lakes could be very beneficial. Intensive fish management seems essential. We have asked visitors to western Wilderness about many management options and one of the most unpopular was "natural fishing--no stocking and barren lakes left barren."

Wildlife habitat could be improved through practices such as prescribed burning, creation of small openings, planting some critical food species, and so on. Wildlife management in backcountry should usually consider nature observation as much or more than hunting. Songbirds and chipmunks can add much to a trip, for example.

Scenery could be enhanced also. Trails should be laid out to take full advantage of views near and far (Shafer and Mietz 1969, Lucas 1971). Beyond this, the quality of recreation could be improved by skillful manipulation: removing a few trees to open a vista, planting flowering shrubs or varieties that have brilliant fall coloring, making a small meadow by a pond, and perhaps thinning a patch of timber to encourage development of a "cathedral grove" of large trees. Adding new attractions, and thus dispersing visitors to new destinations and camping areas, could increase social carrying capacity.

Again, there is need for a range of policies under the backcountry heading--some areas should be modified very little, if at all, and others could gradually be

enhanced very substantially, almost created, especially in areas previously altered by man's use.

Practices to protect or restore sites damaged by use could be more varied than in Wilderness. More use-resistant species could be planted, fertilized, and watered. If advantageous, non-native species could be planted in backcountry, unlike Wilderness.

#### Trail Systems

We have just stressed the importance of making trails conducive to esthetic experiences. Capacity can also be enhanced by laying out trails and adding side trails so visitors explore more country rather than just reach a destination as fast as possible. Trail design also can reduce visibility between parties and thus enhance solitude. One-way loop trails in high-use areas could greatly reduce encounters between parties

#### Use Regulations

In every study cited above that investigated the issue, Wilderness and backcountry visitors were receptive to use controls, more so than managers usually expect (Hendee and Harris 1970, Hendee and Pyle 1971). Regulation, if and when necessary, should not be delayed by visions of violent public opposition. Manipulation of access--making access more difficult or time-consuming by blocking off the last few miles of roads, for example--ranks first with visitors (Stankey 1973); a mail reservation system ranks second. Absolutely the most unpopular way to regulate use would be for the managers to assign itineraries and campsites (Stankey 1973; Lucas, research in progress).

#### Use Projections

All indications are for continued rapid growth in backcountry use (or potential use, if opportunities for its expression are lacking). Projections for Wilderness use (ORRRC 1962a, USDA Forest Service 1959, BOR 1967), all predicting faster growth than for most types of outdoor recreation, have consistently underestimated the use that actually occurred. Booming sales of backpacking equipment, snowmobiles, and trail bikes are another symptom of recent rapid growth.

All studies show that Wilderness visitors predominantly come from social-economic categories that are growing

rapidly and are projected to continue expanding: urban, well-educated, professional occupations, moderately high incomes. Mechanized recreationists are more often from small towns or rural areas, average or below in education, and from blue-collar occupations (Lucas 1971). These segments of the American population are slowly growing or are declining, and their use potential may level off.

#### SUMMARY AND CONCLUSION

The need for a more dynamic backcountry recreation program is amply documented by a wide variety of research. The gap in the middle of the recreation opportunity spectrum is obvious. It may be difficult to obtain political support for intermediate, compromise positions because both past recreation programs and much of the organized, vocal public have been polarized. Nevertheless, the potential use and public benefits of a variety of backcountry areas cannot be denied.

Although a backcountry recreation program and its social carrying capacity aspects have been outlined, we have drawn mainly on studies of Wilderness visitors. Research is adequate to help formulate new backcountry programs and help managers as they develop first approximations of social carrying capacity. However, more precise, specific guidelines can come only from future research addressed directly to different kinds of backcountry areas and their uses. We emphasize again the importance of clear objectives in developing new areas and evaluating their capacity.

Cooperative pilot projects involving area managers and researchers are particularly necessary. New programs could be developed from present knowledge and imaginative, creative, new ideas. At the same time, plans could be made to objectively monitor public response in terms of use, satisfaction, and attitudes about specific management actions. Substantial benefits for the public could come out of this type of partnership.

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# ECOLOGICAL CARRYING CAPACITY

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**ABSTRACT.**--Carrying capacity can be defined only in terms of the management objectives for a specific area. Management objectives should be determined by interagency regional planning so that each agency provides only those recreation opportunities that correspond best to its mission and to the nature of the landscape under its jurisdiction. Within management constraints, sites can be hardened to provide the recreation opportunity called for by the management objectives. The problem often is that the hardening process alters the character of the area beyond the limits of acceptable change for the recreationist. More research is needed to provide hardening techniques that will protect the resource yet not alter the recreational character of the area.

In traditional ecological usage, carrying capacity is a complex concept broad in meaning, but it can be defined in a general way as the total number of individuals of a species that can live in an ecosystem (or habitat) under certain conditions (Knight 1965). The "certain conditions" causing the complexity include individual, population, and environmental (weather, food, other organisms, and a place to live), interactions (Krebs 1972), and feedback mechanisms.

In man-dominated or controlled ecological systems the term has come to mean the number of a species the environment can support on a sustained yield basis (for example, the number of cattle per acre per year). This concept of carrying capacity has been traced by Wagar (1964) back to man's earliest history with regard to the capacity of the land to produce enough food for the human population.

In recreation, carrying capacity has received much attention only since the 1960's (Brandborg 1963, James and Ripley 1963, Lucas 1964), but the concept is much older. Overcrowding in national parks and consequent loss of wildland values were noted in the 1930's by Adams (1930), Meinecke (1932), and Leopold (1934). And Wagar (1964) recognizes the same concept in the restriction of hunting rights to the nobility during the reign of Charlemagne (768-814 AD).

Taking earlier attempts at defining recreational carrying capacity into

account, Lime and Stankey (1971) defined it as "... the character of use that can be supported over a specified time by an area developed at a certain level without causing excessive damage to either the physical environment or the experience of the visitor." This has been paraphrased by Frissell and Stankey (1972): "What are the environmental and social consequences of a given level of use over a certain period of time?"

Lime and Stankey distinguish three aspects of recreational carrying capacity: management objectives, visitor attitudes, and impact on the physical resource. The impact on the resource (ecological aspect of recreational carrying capacity) is our specific topic, but as Lime and Stankey point out, the three aspects are interdependent, no one being necessarily more important than another. Because one aspect cannot be discussed without occasional reference to the other two, some of this discussion will overlap topics assigned to other participants in this symposium.

## RECENT LITERATURE

Ditton (1969) in a detailed review of literature dealing with water as a recreation resource states that the most definitive "... state-of-the-knowledge..." publication on recreation carrying capacity to 1969 is that of Chubb and Ashton (1969). Ditton sees good agreement about the physical, social, attitudinal, and

behavioral factors involved in establishing optimum recreation use (carrying capacity) as expressed by Anderson (1959), Lucas (1964), Wagar (1964), and Chubb and Ashton (1969).

In their chapter on the nature of recreational carrying capacity Chubb and Ashton (1969) enumerate as site factors: a) geology and soils (as they affect drainage and vegetation; i.e., the more fertile soils are able to withstand high levels of use and better maintain a satisfactory ground cover than less fertile soils), b) topography and aspect (as they affect slope and thus soil erosion and microclimatic influence on the flora and fauna), c) vegetation (its ability to tolerate varying intensities and types of recreational use), d) climate (as it influences length of season available for a given recreational use), e) water (availability for domestic, irrigation, and recreational use), and f) flora and fauna (especially where they are the basis for the recreational use of an area). These factors all play an important role in determining the ability of a site to withstand recreation pressure.

Lime and Stankey (1971) have published the most recent extensive and intensive review of the recreation carrying capacity literature and an annotated bibliography (Stankey and Lime 1973). They conclude that there are many possible capacities for a given recreation area and that determining capacity requires a consideration of the values of a variety of publics and the area's resource resistance to recreational use. They emphasize that recreationists who appear superficially similar may not have identical recreational needs or perceptions of the environment (they may not perceive environmental degradation the same either). These authors recommend that administrators use alternatives other than rationing to manage for a given carrying capacity; for example, site management (barriers, hardy vegetation, etc.), regulating visitor behavior (zoning, reservations, etc.) and modifying visitor behavior (fees, information services).

Since Lime and Stankey (1971), Tivy's (1973) literature review on recreational carrying capacity and several other conceptual papers have appeared that add

depth to the ecological aspect of recreational carrying capacity (Conservation Foundation 1972, Lloyd and Fischer 1972, Fisher and Krutilla 1972, Frissell and Stankey 1972, and Hopkins *et al.* 1973).

Tivy (1973) summarizes the most significant and relevant USA research through 1971 on the problem of defining and determining recreation carrying capacity. The paper also contains a limited annotated bibliography on carrying capacity. Tivy concludes that recreation cannot be compared directly with other types of land use in terms of land or capital intensity. She compares recreational land use to use of land for animal grazing and concludes that just as the sheep farmer, cattle rancher, and gamekeeper need to know the stock carrying capacity of their lands, managers of recreational land must know what the results of varying intensities of recreational use will be.

Although the Conservation Foundation report (1972) is addressed specifically to national parks, two aspects of the paper seem applicable to ecological carrying capacity on any wildland. First, the report refers to a physical carrying capacity: "... the effect of visitation on the nonliving aspects of the habitat"; i.e., the ability of a particular terrain to resist trail erosion, but also the ability of the terrain to "absorb" trails, roads, and other man-made objects. It also refers to an ecological carrying capacity as "... the effect of visitors on park ecosystems."

From an ecological point of view, the two capacities actually cannot be separated. The nonliving and the living by definition are both part of an ecosystem. An alternative interpretation might be that it attempts to differentiate the macro versus the micro impact of recreational use on the resource. Thus, the impact of use on a particular trail or campground may be quite severe, but if it constitutes only a very small percentage of the total resource of the recreational area, it can be viewed as a micro-impact problem. And the question of how many trails, roads, campsites, etc., the whole recreational area can contain without degrading the area as a recreation resource is a macro impact. The latter seems to be more of a subjective evaluation of an objective setting for an area.

A second pertinent aspect of the report is the idea that recreation management of an area should be based on a judgment of the appropriate carrying capacity and that this judgment should be a *political one* "... grounded in both expert evaluation of the resource and in the interests of the people who use or could use the park." The idea that the carrying capacity be based on a political judgment did not originate with this report but perhaps it is stated more emphatically than before. Lime and Stankey (1971) say that "... capacities can be defined only in light of the objectives for the area in question" and they too discuss the role of people's interests in setting capacities and objectives.

Lloyd and Fischer (1972) emphasize an aspect of ecological carrying capacity discussed by earlier workers (Wagar 1966, Lime and Stankey 1971); i.e., the concept that there is a continuum of recreational demands from dispersed to concentrated types. Lime and Stankey indicated that providing a wide range of recreational opportunities to choose from within a region will help visitors maximize their enjoyment. Lloyd and Fischer suggest criteria for doing this, including space requirements, participant interaction, participant objectives, the character of sites and facilities, accessibility, and mode of transportation. Lloyd and Fischer feel that people's preferences and objectives are the crucial considerations in providing any kind of recreation.

Fisher and Krutilla (1972) discuss a way to define and measure carrying capacity in wilderness areas in accordance with economic principles. They assume that in wilderness the factor that limits capacity is user perception of a quality experience (solitude) and not user impact on the resource. They suggest capacity be set through a type of cost-benefit analysis of congestion. They relate the benefits of successive days of wilderness use to the number of user encounters. As a measure they use the amount that wilderness users would be willing to pay for differences in the quality of the experience defined in terms of freedom from congestion.

Frissell and Stankey (1972) develop in more detail an idea expressed earlier by Lucas (1964), that physical deterioration of the resource is more likely to be in-

directly limiting by reducing visitor satisfaction than by deterioration of the site itself. Thus, the physical capacity for use might be easily raised by hardening sites, etc. (assuming sufficient funds). Frissell and Stankey emphasize that there are "limits of acceptable change" imposed through user perception (at least for wilderness users) that may be more restrictive in terms of capacity than actual physical or ecological limits.

Hopkins *et al.* (1973) are primarily concerned with recreation planning from an economic viewpoint, but their comments also apply to ecological carrying capacity. They stress that managers need to have clear agency objectives before analyzing recreational alternatives.

## APPLICABILITY OF THE RESEARCH

Based on the review of earlier papers and the recent conceptual papers described above, perhaps we can agree that the current "state-of-the-knowledge" of ecological carrying capacity is about as follows:

There is a continuum of recreational demands from dispersed to concentrated types for any landscape.

Over any broad landscape there is a corresponding continuum of response levels possible by the resource (ecosystem) to recreational demands that might be imposed. These responses are what determine the ecological carrying capacity of a recreation area.

Researchers recognize that there are some types of recreation use within the demand continuum that conflict with each other (snowmobiling and snowshoeing). The conflict may involve the nature of the experience each type of user is expecting to derive from his activity or it may be that the activities themselves cannot use the same piece of land (snowmobiling and cross-country skiing). In the same sense, there are possible severe conflicts between activities within the demand continuum and the resource (off-road recreation vehicle use over fragile soils, etc.).

The time to match potential recreation uses with each other and with the resource is in the planning stage when management objectives are being defined. Managers

will soon be expected to provide the appropriate recreational opportunities on the most appropriate areas and not (as may often have been the case in the past) provide for demands where users have "created" them through custom or tradition.

Through planning, improper matching of use and resource can be avoided and a minimum hardening of sites required to withstand the recreational impact. Thus, although ecological carrying capacity can be a limiting factor, within management constraints (laws, directives, finances, etc.) sites can be hardened to provide the type of recreation called for by management. The problem arises in the way the site is hardened. The types of facilities and designs for protecting the resource often alter the character of the area to the point where it becomes unacceptable to the user. The user is displaced and must find other areas that will satisfy his need.

By defining management objectives on a regional basis, we can provide more recreational opportunities within the continuum of recreational demands and avoid more resource conflicts. We should recognize that each public agency and the private sector cannot (or need not) provide all types of recreational opportunities. Interagency regional planning could result in each public agency, and the private sector, providing the kind of recreation that best meets the agency mission and best "fits" the nature of the resource under the agency's jurisdiction.

#### FUTURE RESEARCH

Research is needed to provide techniques and information for regional interagency planning so that landscapes of differing ecological capability can be matched more closely to recreational demands. Matching will reduce both social and resource incompatibilities while maximizing recreational opportunities.

Research on the techniques of hardening sites is needed so that: a) a minimum of energy (money) is required; b) any change in the character of the area is acceptable to users; and c) the resource is protected.

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## ECOLOGICAL IMPACTS OF OFF-ROAD RECREATION VEHICLES

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**ABSTRACT.**--More than 5 million off-road recreation vehicles (ORRV's) are in existence today in the United States. Negative ecologic and sociologic impacts are inevitable and resource managers must be prepared to deal with them. Most land managers deal with broad landscapes, and thus must have information relating to ecosystems. In the case of snowmobiles, research is still rudimentary and no definitive studies of their impact on ecosystems have been done. While not considered in this paper, literature on other types of ORRV's is also probably lacking. Snowmobile impacts on the ecosystem can be inferred from a review of the literature on the structure and mechanics of snow and the significance of snow in the lives of many small mammals and the predators who feed on them. After a review of this literature, a prudent land manager would conclude that snowmobile traffic must be contained within certain areas and not be allowed a free run on the landscape.

### INTRODUCTION

An off-road recreation vehicle (ORRV) is any motorized vehicle capable of travel on or over land, water, snow, ice, marsh, swampland, or other natural terrain without benefit of road or trail (U.S. Dept. Interior 1971). There are at least four different types of ORRV's: the 4-wheel-drive vehicle, the motorcycle, the snowmobile, and most recently, the all-terrain vehicle (ATV).

Significant production of ORRV's began in the midfifties (U.S. Dep. Interior 1971, Doyle 1973). Since then production of ORRV's has increased at a phenomenal rate. Motorcycle and snowmobile sales in the United States are two examples as seen in the following tabulations:

<i>Year</i>	<i>Motorcycles sold</i>
1955	20,000
1960	60,000
1970	1,430,000
<sup>1</sup> 1980	1,700,000

<i>Year</i>	<i>Snowmobiles sold</i>
1960	<500
1963	10,000
1970	445,000
1973	530,000
<sup>1</sup> 1976	576,000
<sup>1</sup> 1979	1,000,000

The rate of increase is predicted to drop significantly by 1980, since the current base of over 5 million ORRV's is so large (U.S. Dep. Interior 1971).

Because different types of ORRV's run on different kinds of surfaces (the ATV may be an exception), the distribution of ORRV's on the total landscape is patchy. Snowmobiles, for example, are restricted to the 31 snowbelt States, and even there distribution is anything but uniform. Of 1.2 million snowmobiles registered in 1972, 682,000 (56 percent) were in the States of Michigan, Minnesota, and Wisconsin.<sup>2</sup>

Because there are so many ORRV's in the United States, and because some types are concentrated in relatively small areas of the total landscape, there is ample reason to consider the impact of these vehicles on ecologic systems. There is also ample reason to consider possible conflicts between users and nonusers of ORRV's.

The Executive Branch of the Federal Government recognized that negative ecologic and sociologic impacts are inevitable with so many mechanized vehicles. In February 1972, President Nixon issued Executive Order #11644 "... to establish policies and provide for procedures that will ensure that the use of off-road vehicles on public lands will be con-

<sup>1</sup> Predicted.

<sup>2</sup> Statistics from Int. Snowmobile Ind. Assoc.

trolled and directed so as to *protect the resources* of those lands...and to *minimize conflicts among the various uses of those lands*" (italics added).

ORRV's are not going to go away, and indeed they shouldn't for they have positive recreational values. However, something must be done to make ORRV use compatible with the environment desired for nonmechanized recreation. Legislation is only a partial solution for resolving conflicts between users and nonusers of ORRV's. In addition to sanctions or laws, what is needed is a sensitive approach by resource managers utilizing the science and skills of ecology, engineering, the landscape design arts, and the behavioral sciences.

The purpose of this paper is to review the body of environmental knowledge on one type of ORRV--the snowmobile--and to show by example how this information could best be used by resource managers now--without waiting for more definitive research to be done. This exercise should also prove instructive for managers concerned with other types of ORRV's.

While we are here dealing only with environmental impacts of ORRV's, we should recognize the importance of coming to grips with the behavior and experiential aspirations of ORRV users. Only when we know what users are seeking from their experiences can we begin to effectively control the way they use landscapes. The research necessary to generate this knowledge is now almost totally lacking. Hopefully, social scientists will soon be undertaking behavioral studies of ORRV users.

#### INFORMATION NEEDED

Resource managers are already aware that any substantial intrusion by man on a natural scene is disruptive. They know that physical compression of the surface affects the underlying soil, snow, plants, and animals. Whether man makes a beaten path by foot or on snowmobile, the surfaces transected will be affected in some negative way; these negative effects, known as *proximal* or *point* impacts, are often immediate and dramatic. Moreover, at some stage use may increase so drastically that the ecological insults become intolerable and the system begins to malfunction. These malfunctions are the *ultimate* or *system* effects that

should primarily concern resource managers.

*Point* and *system* effects can be further illustrated by a field whose snow cover is compacted by intensive snowmobiling, an apparently common occurrence around metropolitan areas (fig. 1 in Schmid 1971). A point effect might be the decline in weight of vegetation the following growing season. A plausible consequence of the snow compaction and phytomass decline might be large-scale mortality of field rodents. Ultimately, the decline in rodents could reach up a food chain to affect raptorial birds who feed on field rodents, and thus affect an entire system. System effects would usually not be observable for some time, perhaps years, after the initial disturbance.

Man on foot, snowshoes, or touring skis could, however pure his intentions, cause similar disruption of a system. But snowmobiles have enabled him to do it at a much faster rate. Consider, for example, the area compacted by a ski tourer on 3-inch-wide skis traveling at 6 miles per hour for 10 hours compared with a snowmobile having a 30-inch-wide tread traveling at 20 miles per hour for 10 hours: the skier would compact 4 acres while the snowmobile was compacting 61 acres. Another comparative illustration is given by Pruitt (1971) who in a small but neat study found that the morphological and insulative characteristics of a snowfield had changed significantly after two passes with a snowmobile, while it took 50 passes by people on snowshoes to make an equivalent change in the snow (table 1).

It is the job of research to devise a theory which will give managers a basis for predicting where ecologic dysfunction is apt to appear. This is especially critical in this era of the ORRV when rates of impact are greatly accelerated over times when recreationists traveled the unroaded landscape on foot. Managers need predictions of ultimate or system effects. Knowledge of the result of point impacts may be crucial for systems scientists but will be of little practical value to managers.

Table 1.--Snow-compaction effects (adapted from Pruitt 1971)

Type of compaction	Thickness	Density	Hardness	Heat transmission
	Cm		Gr/Cm <sup>2</sup>	Cal/cm <sup>2</sup> /sec/°C
Undisturbed snow	33	0.14-0.20	4- 80	1.52 x 10 <sup>-4</sup>
One pass with snowmobile	14	0.26	3,000	2.49 x 10 <sup>-4</sup>
Two passes with snowmobile <sup>a/</sup>	23	0.36	7,000	6.4 x 10 <sup>-4</sup>
Fifty "people passes" on showshoes	15	0.39	2,500-4,000	6.4 x 10 <sup>-4</sup>

a/ After drifting.

## AVAILABLE INFORMATION

The scientific literature on the impact of snowmobiles on life systems is limited; the first reports of original research did not appear until 1971 (Wanek 1971a). An intensive search revealed but 16 reports of original research (table 2) with some degree of scientific merit; that is, the authors used the scientific "method." Of the 16, seven were progress reports, five appeared in the proceedings of symposia, two appeared as abstracts, one appeared in a semipopular magazine, and only one appeared in a scientific journal.

While many of these studies were exceptionally well conceived and conducted, none was ecosystemic in scope. All were limited in terms of factors studied (table 2). A review of current studies of environmental impacts of snowmobiles promises few definitive reports in the near future.<sup>3</sup>

In summary, the literature answers a few questions about the effects of snowmobiles on parts of systems but none on total systems. I suspect the same would hold true as regards other types of ORRV's.

## AN ALTERNATIVE

Even though we do not know the system effects of snowmobiles, it is pos-

sible to infer some of these effects from the ample existing literature on snow irrespective of snowmobiles--in Bergen 1971; Curl, Hardy, and Ellermeier 1972; Gold 1956; Kingery 1963; Mantis 1951; and Maykut 1969, to name a few.

We know that deep and fluffy snow (i.e., snow of low density) is a good insulator. For instance, in east central Minnesota the nocturnal air temperature 15 cm (6 inches) above the snow surface can be -41° C (-40° F), while under 44 cm (18 inches) of snow the ground surface is a constant -4° C (24° F) (Gullion 1967).

Moreover, the insulation that snow provides is very important to many small mammals (like mice and shrews) which spend most of the winter at the ground and snow interface. The Russian, A. N. Formozov (1946), called our attention to the importance of snow cover and more recent studies have confirmed it (Irving 1972; Pruitt 1957, 1970). For example, the varying lemming in the arctic, the longtail vole of western North America, and the widely distributed meadow vole are all subnivean (living beneath the snow surface). They have "lower critical temperatures" (the environmental temperature at which their heat production must increase above the basal level) ranging from 14° to 29° C (Scholander *et al.* 1950, Beck and Anthony 1971, Weigert 1961). Thus, it is reasonable to assume that mammals as small as these three species would suffer greatly if they could not find winter shelter under deep, fluffy snow. Beer (1961), in fact, did document an apparent die-off of small mammals (mainly the redback vole and the white-footed mouse) in southeastern Minnesota during a winter when there was no snow cover until mid-February.

<sup>3</sup>The author attended a "Snowmobile and Off-the-Road Vehicle Symposium" at Michigan State University in September 1973. Although the papers have yet to be published, the author believes the research is still not ecosystemic in scope.

Table 2.--*Reports of research on the environmental impacts of snowmobiles*

Author(s)	Location of study	Factors studied
Anonymous 1972	SW & NW Wis.	Harvest yields of forages; changes in percent botanic composition; soil compaction
Bollinger and Rongstad 1972	SW Wis.	Noise propagation by snowmobiles; cottontail rabbit; white-tailed deer
Dorrance <i>et al.</i> 1973	E. Central & Central Minn.	White-tailed deer home range in relation to snowmobile traffic and vegetation
Huff <i>et al.</i> 1972	E. Central & Central Minn.	White-tailed deer
Huff and Savage 1972	E. Central Minn.	White-tailed deer; cover-type selection by deer
Jarvinen and Schmid 1971	SE Minn.	Small mammals in an old field
Lavigne 1973	W. Maine	Movements of white-tailed deer in yards
Marshall 1972	SE Minn.	Invertebrates in an old field
Neumann and Merriam 1972	SE Ontario	Characteristics of snow; woody vegetation; snowshoe hare; red fox
Schmid 1971, 1972	SE Minn.	Snow density and compaction in an old field; small mammals
Soom <i>et al.</i> 1972	SW Wis.	Noise propagation by snowmobiles; cottontail rabbit; white-tailed deer
Wanek 1971a	N. Central Minn.	Soil temperature; woody vegetation
Wanek 1971b	N. Central Minn.	Soil temperature, bacteria, and fungi; woody vegetation
Wanek 1972	N. Central Minn.	Soil temperature and bacteria; woody vegetation; harvest yields of forages
Whittaker and Wentworth 1971	NE Maine	Harvest yields of forages

Because mechanical compaction reduces snow depth, increases thermal conductivity and snow density by destroying air spaces (Jarvinen and Schmid 1971; Schmid 1971, 1972), we could infer a negative impact--in this case mortality in some small mammal populations--as a result of man-induced snow compaction. We could arrive at this conclusion without recourse to research reports on the snowmobile and its impact on small mammal populations.

In our example, we feel reasonably secure in extrapolating our conclusions

to include the snowmobile. Schmid (1971), for example, has presented conclusive evidence that heavy use of fields by snowmobiles will increase snow density to values between 0.45 and 0.49 g/cm<sup>3</sup> (the maximal or critical density of snow is about 0.59 g/cm<sup>3</sup> (Maykut 1969)). Schmid concluded that "these densities are so high that it is doubtful if any movement of small mammals could occur at the snow-ground surface." In addition, Jarvinen and Schmid (1971) and Schmid (1972) gave preliminary but reasonably conclusive evidence that populations of subnivean mammals in fields

compacted by snowmobiles dropped to a point approaching extinction.

We might go further than our conclusion that compaction of subnivean habitats by snowmobiles could cause significant mortality in populations of small mammals. It is well documented that certain raptors, especially the hawks and owls, rely heavily on small mammals as a food source during winter and early spring. In a study in southern Michigan, meadow and white-footed mice comprised 91 percent of the winter food of great horned owls, and small mammals in general (mice, rats, shrews) formed 99 percent of the red-tailed hawk's diet (Craighead and Craighead 1956). Because these raptors lay eggs in late winter and early spring (the great horned owl, for instance, may be incubating its clutch in early February) and see them hatch during March or April, it is critically important for them to have an adequate food supply during that period. While I have not found documentation of the effect of a die-off of small mammals, such as Beer (1961) reported, on the productivity of raptors, it seems reasonable to conclude that their productivity would suffer significantly.

A prudent natural resource manager might accept these documented bits of evidence, since the underlying assumptions appear solidly based on biological and physical principles, and conclude that compaction of a large area by snowmobiles would significantly affect food chains which end in raptors. If he were willing to be slightly less prudent, he might go further and conclude that negative feedback would eventually occur and the "balance" between prey and their predators would be irreparably altered.

Similar arguments might be developed for events more subtle than mechanical compaction of snow and subsequent food chain effects. The northern bald eagle, for instance, begins its courtship and nesting in late February and early March. Some eagles--perhaps the majority of eagles--are extremely sensitive to human intruders and may abandon their reproductive efforts when disturbed. Although this event has not been conclusively documented, conservative resource management would direct snowmobiles and other recreational activities away from eagle territories.

## SUMMARY

ORRV's are seemingly here to stay. Without question, they cause negative impacts on ecologic systems, but, then, so do other types of recreation, as well as agriculture, roadbuilding, urbanization, etc. Because ORRV's are much faster than man on foot they greatly accelerate the rate of environmental degradation.

This is akin to the phenomenon termed "future shock" (Toffler 1970); that is, the future (in this case, the time it takes to arrive at intolerable levels of environmental degradation) is arriving at a much faster rate than ever before. It should not be surprising that the manager's reaction time must decrease over what it was in the past.

Resource managers should be concerned with landscapes and ecosystems rather than with point impacts or small pieces of the landscape. Unfortunately, the impact of ORRV's on ecosystems will probably not be well documented for some years.

Nevertheless, there is an extensive separate literature on snow which should allow for some "best guesses," at least for impacts by snowmobiles. We can seriously question the contention of a recreation land manager in Minnesota who stated, "...the so-called ecological impact of snowmobiles has been very much exaggerated...with over 30,000 hours of fieldwork during the past 6 years and not one damage case reported of any significance, we doubt that there is a snowmobile problem" (Shuldiner 1973).

We know that when significant areas of landscapes are repeatedly traversed by ORRV's there is a good *chance* of serious dysfunction in the ecosystem. Of course, the level of chance that a manager is willing to accept is also influenced by social and political factors. I believe "systems safe" patterns for ORRV traffic could now be designed using available information on ecologic functions and processes. One way would be to restrict traffic to a few existing roads and trails.

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## RECREATION AND/OR NATURE PRESERVATION

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**ABSTRACT.**--Numerous objectives have been given for nature reserves, from the preservation of organisms and ecosystems for their intrinsic and scientific values to providing areas for public education and recreation. In response, society has devised several types of preservation areas, ranging from strict nature reserves where recreation is excluded or severely constrained to Wilderness Areas and natural parks where public recreation and education are important goals. In recent years there has been a tendency to equate ecosystem preservation with Wilderness or with strict nature reserves. But, in fact, it is possible to preserve ecosystems within a range of facilities for public use. Size constrains such development more than the kinds of facilities themselves. It is essential that facilities be compatible with both objectives and size. Consumptive use of natural resources and certain heavy-impact recreational uses (such as all-terrain vehicular travel) must be excluded from all types of nature reserves. Active preservation programs are often needed to restore or maintain vital ecosystem processes where man has altered the system. Restoration of fire or missing predators are examples. For areas where both recreation and preservation are objectives, educational and interpretive programs can make these uses more compatible.

### INTRODUCTION

The debates between advocates of "multiple use" and the "preservationists" have been increasing throughout the United States and Canada in the last 20 years. Much of the discussion centers around the allocation of wildlands for commodity production (timber, minerals, grazing, etc.) as opposed to ecosystem preservation. But another theme is also being heard with increasing frequency and intensity. Is recreational use of nature preservation areas, in fact, compatible with preservation? It is this question I want to explore here. I ask you to take a careful look at the actual degree of compatibility between recreation and preservation as land uses and human activities.

I speak to you as a confessed preservationist, as an avid wildlands recreation user, and as an ecologist who has tried to come to grips with certain very real technical problems in nature preservation programs. I hope this perspective will stimulate useful dialogue. The questions I want to help us address are these:

(1) What public objectives can be served by nature reserves of various kinds, including both those where recreation is

traditionally allowed, and those where it is not?

(2) What kinds of nature reserves and related preservation-oriented areas do we have, at present, both where recreational use is allowed, and where it is prohibited?

(3) Are wilderness and preservation synonymous?

(4) What is the effect of size on the compatibility of recreation and preservation?

(5) What kinds of recreational use are compatible with preservation, and where can such uses be best accommodated?

(6) Can we identify needs for educational and interpretive programs to increase the compatibility of recreational use in appropriate preservation areas, and to achieve stated public objectives?

My questions indicate that I see no absolute dichotomy between recreation and preservation. And if we take a reasoned look at the public needs to be served, I think we can identify both the situations that call for separation of uses and those that require specified kinds and levels of recreational use. There is really a continuum of possible objectives and uses. Once this is perceived, I

think the necessary management direction becomes much clearer.

## PUBLIC OBJECTIVES TO BE SERVED

A wide spectrum of possible public objectives has been asserted for various types of nature reserves, parks, wilderness areas, and related special areas where nature preservation is at least a partial goal (Bormann 1966, Brower 1960, Darling and Eichhorn 1967, Dasmann 1973, Falls 1967, Franklin and Trappe 1968, Franklin *et al.* 1972, Heinselman 1965, 1973, Lindsey *et al.* 1969, Littlejohn and Pimlott 1971).

The following list includes most of the ideas usually given:

1. Preservation of unique, rare, or endangered species, natural communities, or ecosystems, simply to prevent their elimination and to maintain the natural diversity of the earth's life system.
2. Providing areas for the scientific study of organisms, plant and animal communities, and their environments in natural systems.
3. Providing gene pools of the native plant and animal species whose genetic stocks have not been manipulated by man.
4. Providing check areas for scientific comparisons with the technologically modified ecosystems of the man-dominated general landscape.
5. Providing areas for the scientific study of large-scale natural ecosystem processes of the kinds detectable only in relatively complete examples of a biotic province. Such areas must be large enough to contain the full range of plant and animal communities characteristic of a physiographic region.
6. Providing areas for use in formal education at all levels from grade school through university graduate programs, including areas suitable for short field trips, extended learning experiences, and outdoor laboratories for graduate research.
7. Providing areas for the education of the general public in understanding natural environments and the ecological problems facing mankind.

8. Providing areas for the aesthetic and psychological appreciation of bonafide natural ecosystems by the public.

9. Providing areas where the public can experience and appreciate the historical background of our civilization by witnessing actual historical settings in their natural state, and by reliving pioneering experiences in a real-life setting.

10. Providing areas where the public can participate in primitive and unconfined types of outdoor recreation in a natural setting away from the sights and sounds of civilization.

Note that this list is more or less ordered with science-related objectives first and public participation objectives second. The latter group is also ordered with the educational and intellectual objectives first and the strictly outdoor recreation objectives last. Now let's look at the kinds of areas our society has devised to meet these objectives.

## KINDS OF RECREATION AND/OR PRESERVATION AREAS

I see five broad classes of preservation areas, each emphasizing a somewhat different combination of the above objectives. There is actually a continuum of objectives and use policies here, but this list should help us see how society is responding to the needs people express:

1. Strict nature reserves
2. Major natural parks and related reserves
3. Wilderness Areas
4. Lesser natural parks and related reserves
5. Special areas.

I intend to include in these classes only those areas or portions of areas where the commercial use of the area's natural resources is prohibited, and where some stated or implicit preservation policy exists. For example, only the present interior zone of the Boundary Waters Canoe Area (about half of the area) actually has a preservation policy, and only the Wilderness Sanctuary of Itasca State Park in Minnesota has a strict policy. The actual ecosystem preservation program may be passive or

active. In many cases it is still only passive (more on this later). I should also observe that there would really be some "double counting" if one were to total up the acreages now committed to each of these classes. For we have *strict nature reserves* within *major natural parks* and *Wilderness Areas*, *Wilderness Areas* within *major natural parks*, and so on.

The distinctions between my five classes need sharpening. Let me do this by listing the following for each: (1) typical names attached to the class, (2) typical ownership patterns, (3) typical size, (4) typical use policies, and (5) some "real world" examples from our region.

#### Strict Nature Reserves

(1) Typical names: research natural areas, natural areas, scientific areas, natural history areas, (a confusing name: wilderness sanctuary).

(2) Typical ownership: Federal, State departments of natural resources, universities and colleges (public and private), The Nature Conservancy (private).

(3) Typical size: 20 to 1,000 acres (over 640 preferred).

(4) Typical use policies: research and education are the dominant intended uses; also may serve as gene pools if large enough and well buffered. Many areas have hiking trails for access--often open to the public for nature appreciation walks. Camping, picnicking, hunting, fishing often prohibited. Use of all motor vehicles and ATV's (all-terrain vehicles) generally prohibited except for necessary research or educational purposes, or on public roads which may exist for access. Structures such as field laboratories and research installations sometimes present. May be fenced and/or posted against public use.

(5) Examples: Cedar Creek Natural History Area, University of Minnesota; Cyrus H. McCormick Experimental Forest, Research Natural Area, North Central Forest Experiment Station, U.S. Forest Service; Passage Island Natural Area, Isle Royale National Park; Helen Allison

Savanna, The Nature Conservancy, Minnesota.

#### Major Natural Parks and Related Reserves

(1) Typical names: National Parks, State parks, Provincial parks.

(2) Typical ownership: Federal, State, Provincial.

(3) Typical size: 5,000 to 500,000 acres (in our region).

(4) Typical use policies: camping, hiking, backpacking, canoe-tripping, boating, cross-country skiing, snowshoeing usually encouraged. Fishing permitted. Hunting usually prohibited. Nature appreciation often encouraged through interpretive programs. Educational and scientific uses encouraged. Serve as major gene pools. Snowmobiles and outboard motors may or may not be allowed. ATV's prohibited except on some roads. Auto roads may or may not be present, depending on nature of the park's resources and development policies. Auto campgrounds, roadside picnic areas, latrines, administrative structures, and public service facilities often present (may be operated by concessionaires). Back-country campsites often constructed, may include simple trail shelters. Developments typically in enclaves, with large expanses of undeveloped natural ecosystem areas separating developed sites. May contain designated *Wilderness Areas* or *strict nature reserves*.

(5) Examples: Isle Royale National Park, Michigan; Quetico Provincial Park, Ontario; Porcupine Mountains State Park, Michigan.

#### Wilderness Areas

(1) Typical names: wilderness area, canoe area, or (portions of) wildlife refuges.

(2) Typical ownerships: Federal, State, Provincial.

(3) Typical size: by law, over 3,000 acres in Michigan, and generally over 5,000 acres for areas designated under the U.S. Wilderness Act of 1964. There

are exceptions to these minimum area guides, but in practice most areas exceed 10,000 acres. The actual maximum size of individual units now present in the north central region that fit the concept is about 500,000 acres.

(4) Typical use policies: backpacking, hiking, canoe-tripping, cross-country skiing, snowshoeing, nature study encouraged. Fishing permitted. Hunting may or may not be allowed. Educational and scientific uses encouraged. Serve as major gene pools. Outboard motors and snowmobiles normally prohibited but in our region there are exceptions. Landing of aircraft, use of automobiles and ATV's normally prohibited. All vehicular roads normally excluded. Hiking trails, portages, and simple permanent campsite facilities often provided. Essentially no permanent structures permitted (administrative cabins sometimes are an exception--most are being phased-out). Differ from *major natural parks* chiefly in prohibition of all roads and mechanized travel and all kinds of structures. May in fact be a designated portion of a *major natural park*; may contain *strict nature reserves*.

(5) Examples: most of Isle Royale National Park, Michigan; much of Quetico Provincial Park, Ontario; much of the interior zone and some of the portal zone of the Boundary Waters Canoe Area, Minnesota, and just designated, most of Porcupine Mountains State Park, Michigan.

#### Lesser Natural Parks and Related Reserves

(1) Typical names: State parks, county parks, city parks, wildlife refuges.

(2) Typical ownership: State, county, municipal, sometimes Federal.

(3) Typical size: 20 to 5,000 acres.

(4) Typical use policies: day hiking, camping, boating, cross-country skiing, snowshoeing, and nature study usually encouraged. Picnicking and fishing usually permitted. Hunting usually prohibited. Outboard motors often allowed. Snowmobiles and ATV's often prohibited, except on roadways. Auto campgrounds,

picnic areas, and back-country campsites often constructed. Public roads often present. Administrative structures, latrines, and public service facilities often present. Scientific and educational values may not be emphasized, but may exist. Could serve as gene pools if large enough and well buffered.

(5) Examples: some sections of Itasca State Park, Minnesota (beyond the Wilderness Sanctuary); Nerstrand Woods State Park, Minnesota.

#### Special Areas

(1) Typical names: ecological areas, botanical zones, botanical areas, geological areas, Wild Rivers, etc.

(2) Typical ownership: Federal, Provincial, State, private.

(3) Typical size: 5 to 5,000 acres.

(4) Typical use policies: extremely variable. The only thing in common here is the temporary or permanent exclusion of commercial uses of the natural resources. Many such areas are either too small to fit the other categories, or their policies are in limbo for various reasons. Many are really unofficial examples of one of the first four classes above.

(5) Examples: LaRue-Pine Hills Ecological Area, Shawnee National Forest, Illinois; The Botanical Zone, Sylvania Recreation Area, Ottawa National Forest, Michigan.

#### WILDERNESS AND PRESERVATION NOT SYNONYMOUS

There has been a tendency in recent years for the public and even some professionals to equate the term "wilderness" with "preservation" of nature. This has undoubtedly occurred because of the great social pressures and debates over the need for more formal *Wilderness Areas* in the sense I used this term above. But the original term, as applied by Aldo Leopold, Robert Marshall, Howard Zahniser, Olaus Murie, Sigurd Olson, and others, was used in the sense I have used it above. It would be wise for agencies and the public not to apply the term to very small areas, or to areas where certain kinds of public use developments are allowed.

An area does not have to be free of all roads, auto campgrounds, public service facilities, and so on, to be dedicated largely to the preservation of nature. These kinds of development often bring pressures for incompatible uses, and may make preservation more difficult, but they do not *of themselves* preclude preservation of the flora and fauna beyond the areas directly impacted, and a reasonable buffer zone. Extensive discussions of this problem appear in Darling and Eichhorn (1967), and in the Conservation Foundation's recent report (1972). The problem is in achieving the stated public objectives for preservation of the natural ecosystem while at the same time providing easy public access to permit as many people as possible to experience that ecosystem. It can be done, but the management techniques required are very different from those permissible in *Wilderness Areas*.

#### EFFECT OF SIZE ON COMPATIBILITY OF RECREATION AND PRESERVATION

The larger an area the more recreational use it can absorb without seriously compromising nature preservation objectives. Yellowstone National Park is a clear example. In spite of hundreds of miles of auto roads, dozens of large campgrounds, hotels, motels, and service facilities, most of the park remains a pristine wilderness that fits the most exacting criteria for *Wilderness Areas*. If you doubt this, I suggest you put on a pack and take to the trails! The ecosystems of the back country are little affected by the heavy use along roads. I am not suggesting that the automobile-oriented developments and heavy traffic are desirable, but I think these facts make a point about area size. If these same developments were imposed on a 20,000-acre park instead of a 2-million-acre one, the area's natural environment would be virtually eliminated just by the developments themselves.

The Boundary Waters Canoe Area is another example. There are more than 2,000 wilderness campsites on remote lakes in this area. Many of them have a steel fireplace grate, a simple box-style latrine, and (some) even tables.

Many have been heavily used since the voyageur's era. But these campsites have an average impact area of less than one-half acre each. The total area directly impacted by such sites is therefore less than 1,000 acres. In a 1-million-acre Wilderness this is less than one-tenth of 1 percent of the area. Including portages and trails in addition, I doubt that visitors to the BWCA directly impact more than one-half of 1 percent of the area. Because of the nature of the terrain, the density of the vegetation, the fact that most travel occurs on lakes and streams, and the great size of the area, the visitors are really no threat to the natural vegetation of the area except on the campsites themselves. One can and should view these campsites as small developed sites that are necessary to achieve important public objectives for the area. There may be too many visitors with respect to the psychological experience of wilderness, and too much noise and conflict with motors and snowmobiles for the same reason. But it is simply not true that a significant proportion of the land ecosystems of the BWCA are being substantially damaged by the visitors. The campsites are "windows to the Wilderness" that serve an important function. Rotating campsites will damage more ecosystem area than simply hardening the sites that are well situated, and accepting some loss of their natural character.

But the converse of these examples poses a very different problem. If one attempts to preserve nature on very small tracts, then very little--or only very tightly controlled use--can be tolerated, or the natural environment could literally be trampled to death. At most, limited trail development, with "keep on the trails" signs are required. Campsites and picnic areas are clearly incompatible. I am thinking here of areas in the 5- to 200-acre size range. Very good judgment is necessary to set the permissible levels of use and development for intermediate-size areas.

#### WHAT RECREATIONAL USES ARE COMPATIBLE WITH ECOSYSTEM PRESERVATION?

It should be clear from my listings of possible objectives and classes of areas that there is no clear answer to

this question. It depends largely on the objectives, size, and ecosystem characteristics of the specific area. If the focus is largely on scientific and educational values and especially if the area is small, then few recreational uses are appropriate. For such areas, only hiking trails seem permissible, and in some cases even these should be excluded. Camping and picnicking are inappropriate in such areas.

But if the objectives include the aesthetic appreciation of nature, the ecological education of the general public, and the physical experiences of travel and living in a natural environment, then public use is necessary to achieve these objectives. Again, if the area is large, it is quite easy to provide for hiking, backpacking, canoeing, tent camping, cross-country skiing, snowshoeing, and other light-impact uses that get the public into the ecosystem where these objectives can be realized. If very easy access is desired to make the area available to the very young, the elderly, and those without the inclination (or the time) to participate in such physical activities, then auto access or public conveyances are required. Auto campgrounds could still be excluded if desired.

Certain uses seem clearly incompatible, or at best marginal, in any kind of nature reserve. Among the clearly incompatible I would put the use of ATV's and snowmobiles off designated roads or trails. They probably should be prohibited in all such areas, except on auto roads as a substitute for an automobile. The nature of these vehicles makes their control difficult. Perhaps the only effective way of protecting the off-trail areas is prohibiting the use of such vehicles entirely. Outboard motors are clearly incompatible where the experience of solitude in a natural setting is an objective.

Hunting is a marginal use at best. I happen to be a lifelong and still avid hunter myself, but in most areas hunting is incompatible with preservation objectives because it substitutes the gun for natural mortality factors. The case for carefully controlled hunting in large *Wilderness Areas* is debatable. Such use is permitted in National Forest Wilderness. I suspect the day will come when that, too, must be prohibited. For example, the (illegal) killing of wolves is a common practice in the remote areas

of the Superior National Forest, including parts of the BWCA, even though wolves are an endangered species that exists nowhere else in the "lower 48." The reintroduction of woodland caribou into the BWCA is a very real technical possibility, but I wonder if they would stand a chance while deer hunting is permitted? Where key native predators are missing from the ecosystem it may be necessary to control some herbivores with the gun, or by other means.

Ordinary fishing, with the emphasis on taking home a large catch, also seems a questionable use. Fishing for fun only, or only for actual consumption while using the area, seems much more acceptable. We should be as concerned about aquatic ecosystems as land ecosystems.

#### THE NEED FOR ACTIVE ECOSYSTEM PRESERVATION PROGRAMS

Preservation does not mean that an ecosystem can be put in cold storage! One of my favorite themes is that the natural ecosystems of North America were extremely dynamic. There was constant change. And often these changes were triggered by perturbations of the system by powerful forces such as fires, windstorms, or severe insect epidemics. These things are natural and should not, indeed, probably cannot, be excluded from nature reserves. We must soon revise our management plans and strategies for all kinds of preservation areas, or we will fail to attain their most important objective--the actual maintenance or restoration of the natural ecosystem. All other objectives hinge on the achievement of this one, but this is the one aspect of our programs we often assume will "take care of itself." It won't! (Leopold *et al.* 1963, Heinselman 1970a).

We must stop "cleaning up" blowdowns. And we should not interfere with epidemics of native insects. If fire was part of the natural system, we must try to reintroduce it safely by prescribed, controlled burning if necessary (Heinselman 1971, 1973). If important native wildlife species are missing, but not extinct, we should consider their reintroduction. Predator control and the disruption of population balances by hunting or trapping should be dealt with if they are factors.

In connection with prescribed burning, let me point out one potential prob-

lem that may be avoided by looking ahead. If new structures and service facilities are planned for a fire-dependent ecosystem, we should put them where protection from the necessary fires will be easy. Large expanses without natural firebreaks and within continuous fuel types are obviously poor places.

### NEEDS FOR EDUCATIONAL AND INTERPRETIVE PROGRAMS

The compatibility of recreation and preservation objectives for many areas could be increased by two kinds of information programs:

(1) Educational programs for the general public to help people understand different preservation areas and their appropriate uses.

If people knew in advance of their visits what an area had to offer, what its resource characteristics were, and what the appropriate and inappropriate activities were, most would only visit areas that suited their tastes and trip objectives. This would divert much use that now occurs because people have no real understanding of the public purposes to which given areas are supposed to be devoted.

(2) Interpretive programs to enhance visitor appreciation of the natural ecosystem values of specific areas.

The U.S. National Park Services does a pretty good job in this area, but many fine nature reserves have little or no interpretive literature, and no onsite or nearby interpretive programs. Nature reserves of many kinds can serve vital public needs. But this does not happen automatically. There must be appropriate literature, good maps, films, slide-tape programs, exhibits, self-guided tours, lectures, and other useful aids to understanding the ecosystem and planning a pleasant and rewarding visit. Without these aids, most of us see far less than is really there.

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# APPROACHES TO FORECASTING RECREATION CONSUMPTION

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**ABSTRACT.**--This paper summarizes approaches to forecasting consumption of resource-based outdoor recreation. Although the discussion is oriented toward the quantity of recreation that will be consumed, qualitative aspects of recreation experiences and environments are also discussed. Forecasting models are evaluated in terms of suitability for recreation planning and accuracy of results.

## RECREATION CONSUMPTION MODELS IN GENERAL

### Why Forecast Recreation Consumption?

With growing competition for all forest land resources, decisionmakers are searching for information on which to base present and future resource decisions. Demands on all resources must be anticipated so that current management programs can be adjusted to meet changing needs. Accurate recreation use forecasts are needed to determine what kinds and amounts of recreation facilities are required, as well as how they should be distributed. Such forecasts provide a basis for facility investment decisions and serve as an input to policy formulation. Recreation use forecasts also provide a mechanism with which to evaluate long-term implications of alternative management decisions.

### Problems in Forecasting

Any forecasting model must necessarily reflect uncertainty about future economic, social, and political circumstances. Models developed to forecast recreation consumption may reflect more uncertainty than most. One major problem in developing such models is the lack of useful input data. Such data are difficult and expensive to collect. Compromise is often necessary between the cost of data collection and the accuracy of data obtained. Secondary data sources--the U.S. Population Census, Bureau of Outdoor Recreation, or past surveys are usually relied upon.

Such data are often imprecise and difficult to incorporate into comprehensive models for regional or local planning.

A major problem in constructing models to forecast recreation use is that the elements that determine recreation behavior are poorly understood. The human motivational factors that underlie recreation behavior are complex and are just now starting to receive research attention. Additional research is needed to determine the ways in which various recreation activities provide outlets for satisfying human needs. While participation in most recreation activities is increasing, activities that are inexpensive, provide a desirable "image," allow the participant the opportunity to demonstrate a skill, and use leisure time efficiently are likely to grow at a faster rate in the future.

Most recreation use forecasts assume a constant relationship between consumption and the quality of the recreation experience received. Yet it can be argued that the quantity of recreation consumed and the quality of experience received are at least partially substitutable. Actual consumption can be increased, but the total enjoyment received may actually decrease.

The nature of the recreation "product" also makes forecasting difficult. Recreation planners are most often concerned with a group of activities that make up the total recreation experience or pack-

age. Should models be developed to predict only camping use, or camping use and other activities related to the camping experience? The product, recreation, is not marketable as a unique package, but enjoys a wide range of substitutability in terms of what is placed in the "package."

Restrictive assumptions are often necessary to develop recreation use forecasts. The relationship between future demand and recreation supply is often assumed to remain constant. Management and policy decisions that affect recreation consumption are often assumed to be unchanging, as are other factors that underlie recreation behavior. The impact consumption is seldom incorporated into forecasts. Such assumptions often lead to completely foolish projections, i.e., each individual midwestern resident would spend 1,500 days per year boating on TVA reservoirs, or that people would spend their entire lifetimes camping!

A further problem involves the decision of what to predict. Is estimated total annual recreation consumption a useful measurement? Should peak use be forecasted in user-days or in visitor-days? Or should "use" be defined in terms of total participant satisfaction received--a measure that is not necessarily correlated with actual use? The USDA Forest Service uses visitor-days as a measure of use. New York State uses the recreation consumption on the fifth highest-use summer Sunday afternoon. Other agencies use other measures.

Another problem involved in developing accurate forecasting models is that the recreation experience itself is hard to identify. Clawson and Knetsch (1966, p. 34-36) have argued that the outdoor recreation experience can be broken down into five major parts: anticipation, travel to the site, the onsite experience, travel from the site, and experience recollection. Each of these facets of the recreation experience has an influence on consumption, yet most current forecasting models are concerned only with the onsite experience.

Because of the difficulties mentioned above, it is no wonder that predicting recreation consumption has been

referred to as "the Achilles heel" of recreation planners and managers (Chubb 1967). Yet imaginative approaches, that attempt to incorporate recreation supply variables, user behavior, management procedures, technological change, and qualitative values, have been taken to overcome the problems inherent in recreation consumption forecasting. These will be discussed later in this paper.

## Recreation Demand and Consumption

The outdoor recreation literature contains abundant references that draw a clear distinction between recreation demand and recreation consumption (Chubb 1967, Clawson 1959, and Knetsch 1970). Yet the two terms are often used synonymously. Demand refers to the quantity or units of a good or service purchased at specific levels of price. The economist defines demand as a schedule of prices people will pay for various amounts of goods and services. Clawson and Knetsch (1966) have developed an approach to evaluating recreation demand based on travel and other costs associated with the purchase of a day's recreation. Here, demand has a distinct meaning. Yet, we often read about recreation "demand" that is not really demand at all, but recreation "consumption"--i.e., total seasonal, weekly, or daily attendance in visitor-days, user-days, or some other appropriate measurement unit.

Consumption actually refers to the amount of recreation consumed at the existing level of price and facility supply. Consumption measures do not separate demand and supply conceptually. As Clawson and Knetsch (1966, p. 116) point out,

"...attendance or use figures are the net effect of the existing demand and the existing supply, and should be so recognized. Improper accounting of supply considerations leads to the assumption that people will demand increasing quantities of what they now have, and can perpetuate present imbalances."

In this paper, recreation "consumption" is defined as the amount of recreation consumed at a specific level of recreation supply and price.

## General Characteristics of Predictive Models

A model is simply an abstraction of the real physical world, incorporating the elements that are relevant to a particular process. Some models are intuitive and simple. Others, such as models used to forecast recreation behavior, are very complex and require mathematical abstraction. Development of models to forecast recreation use includes the search for relevant elements that influence recreation behavior, and structuring the relationship between these elements.

Although many variations of recreation consumption models have been developed, most mathematical models take the general form:

$$y = f(X)$$

Where:  $y$  = the predicted amount of a particular recreation activity consumed in visitor-days, use-days, etc., at a specified time in the future.

$X$  = A set of user population characteristics, supply availability and accessibility, and qualitative aspects of recreation experiences and environments.

The symbol of  $f(X)$  is a notation meaning "a function of  $X$ ."

Wide variations exist within the above generalized model. Some recreation consumption models are developed for local predictions, some for regional, and some for national predictions. Some incorporate supply features exclusively, some include user characteristics, and some use both.

Regardless of the particular model, a basic assumption in most empirical approaches to forecasting recreation use is that the underlying structure of the model--the basic elements that determine behavior--is invariable in the long run. Models implicitly assume that processes that will govern recreation behavior in the future will be the same as those acting today (Cicchetti *et al.* 1969, p. 201). Most models also implicitly assume a constant interrelationship between demand and recreation facility supply over time.

### The "Best" Approach

The ideal model for forecasting recreation consumption would provide the

decisionmaker with an exact prediction of the amount and type of recreation use an area is likely to receive at a particular level of facility development and price. The ideal method should be dynamic so that changes in management policy, recreation supply, price, etc., can be incorporated into the model to determine their potential impact on predicted consumption. It should thus provide a framework for management decisions and reflect the consumer decision processes that underlie recreation behavior. The "best" model would have no error.

The ideal method should be flexible so that it can be applied to local, regional, and national planning needs as well as to various kinds of recreation activities or groups of activities. From a practical standpoint, it should be easy to understand, have minimum data input requirements, and require a minimum of personal judgment. It should provide consumption estimates that are related to facility supply decisions and to appropriate planning time horizons. Chubb (1967) would add that destination and origin zones used in modeling recreation consumption should be small enough to provide realistic planning guidelines. To serve as a basis for policy decisions, forecasts should quantitatively relate demand to supply in the same units of measure.

## APPROACHES TO FORECASTING RECREATION CONSUMPTION<sup>1</sup>

### Local, Regional and National Models

#### Extension of Past Trends

Extension of past recreation use trends has been widely used as a method for forecasting use on a local, regional, or national basis. The advantage of the technique is that it is simple to apply and provides reasonably accurate use estimates for short time periods, perhaps up to 5 years. It is most useful where the geographic area serviced by a particular recreation complex has a relatively stable population, and where rec-

<sup>1</sup>For additional information on approaches to forecasting recreation consumption, see Clawson and Knetsch (1966, Chapter 7) and Shafer and Moeller (1971).

recreation supply and management systems have been stable. It is also useful where per capita recreation consumption has been relatively stable.

The application of trend extension for long-run forecasts is restricted by the many simplifying assumptions on which the method is based. First, it relies heavily on a past data series. In many instances, data have not been collected over a long enough period to provide a reliable trend determination. Even where data are available, nonlinear, long-run trend extensions are subject to considerable error.

The trend extension method assumes that the forces that underlie recreation consumption, including facility supply, population needs, and related causal factors, will remain unchanged in the future. The method, therefore, is not based on causality. It assumes that factors that have operated to create recreation consumption in the past will continue to operate in the same way in the future.

The method is not reliable where the composition or "mix" of recreation facilities provided has changed or where new forms of recreation activities are emerging. An excellent example of inappropriate application of trend extension is provided by Clawson and Knetsch (1966, p. 120). They point out that from 1950 to 1960, construction of reservoirs by the Corps of Engineers coupled with technological advances in boat construction combined to produce a tremendous surge in boating activity. They demonstrate that simple extension of the 10-year trend would indicate that, by the year 2000, every citizen would boat on a Corps of Engineer reservoir approximately 2,500 times per year!

#### Informed Judgment

Quantitative models cannot incorporate special insight and the informed judgment of those directly involved with management of a given recreation complex. People who know the history of a particular planning unit, who have observed changing recreation use patterns, who understand resource capabilities, and who can subjectively evaluate the regional political-social atmosphere that is likely to prevail at some future date can contribute a great deal to making use estimates for a particular area.

Recreation use estimates derived from quantitative models can be tempered by informed judgment and special insight. Informed judgement can be used to incorporate into the forecasting process regional changes that are likely to occur and can identify realistic limits to sustained recreation resource capacity.

If relied upon too heavily, of course, informed judgment can create special problems. Individual biases can easily enter into the process and past short-term use trends can be misinterpreted. There is evidence to suggest that resource managers are not always able to perceive consumer interests correctly (Hendee and Harris 1969). Furthermore, rapid turnover in management personnel can create situations where reliable informed judgment is not available.

Informed judgment by itself is not a reliable approach to forecasting recreation consumption. But quantitative models should be developed that can take advantage of informed judgment whenever possible.

#### Extension of Trends in Basic Causal Factors

Gross estimates of future outdoor recreation consumption have often been developed using major causal factors that are thought to underlie recreation consumption. This approach bases forecasts on factors that have accompanied past growth in recreation consumption; e.g., population growth, increases in leisure time, increased mobility, and increased disposable per capita income. Projected trends in these basic factors are related to future recreation consumption.

This approach has some merit in making short-term forecasts (Clawson and Knetsch 1966). However, a major limitation is that many time-related variables are correlated to past growth in recreation consumption. The simple variable "time in years" provides a fairly high predictability base for past recreation consumption. Simply because a variable (e.g., mobility) has correlated with recreation consumption in the past does not mean that it will correlate with it in the future. The approach optimistically assumes that the factors that underlie current recreation behavior are known, and that the relationship between selected

"causal" factors and recreation consumption will remain unchanged in the future.

Like other similar forecasting methods, these projections are subject to gross error. Models that are based on several causal factors do not normally account for the independent effects of each causal factor by itself. The approach does not incorporate behavioral changes caused by shifts in individual interests, goals, or the relative availability of recreation substitutes. These behavioral relationships are assumed to remain constant into the future.

#### Population Characteristics and Recreation Consumption

The method based on projection of basic causal factors has been extended to models that more precisely relate consumption of a particular recreation activity to characteristics of people who currently participate in that activity. Consumer characteristics are then projected to some desired future year, and an estimate of probable future participation is calculated.

The approach is flexible. It can be applied to many types of recreation planning situations and to different recreation activities. It is also dynamic because it attempts to consider simultaneously many factors that underlie the recreation consumption process. Selected components of the predictive models can be changed to reflect different assumptions about future conditions. Changes in recreation supply characteristics can also be incorporated into such models.

The basic model is:

$$y = f(\text{socioeconomic and other user characteristics, distances, attractiveness of supply, and recreation substitutes available.})$$

Where  $y$  is some measure of recreation consumption.

Many different recreation consumption models have been developed that include selected predictor variables. Models have been developed for local, regional, and national application to various kinds of activities and recreation outings. The functional mathematical model--regression--remains the same, however.

Much of the data used to develop regression models has been collected

through national recreation surveys conducted by the Outdoor Recreation Resources Review Commission or later surveys sponsored by the USDI Bureau of Outdoor Recreation.

Using 1960 and 1965 National Recreation Survey data, Kalter and Gosse (1969) developed recreation participation functions for residents of 12 planning regions in New York State. They used 13 regional socioeconomic population characteristics to construct models to predict three kinds of recreation excursions--total overall participation, vacation trips, and day outings--for five recreation activities. The models showed low predictability when compared to actual survey data. Also using National Recreation Survey data, Mueller and Gurin (1962) constructed a recreation activity scale that reflected participation in 11 outdoor recreation activities throughout the United States. They used socioeconomic characteristics to explain behavior.

Gillespie and Brewer (1969) used data collected through household surveys within the St. Louis metropolitan area to construct models that explained the number of water-oriented outdoor recreation activity days participated in per family. Seventeen socioeconomic variables were incorporated in their equations. Resulting models mathematically accounted for 62 percent of the variation in total annual water-oriented recreation activity for the sample group. Compared to other models, their model was relatively successful. Similar results may be obtained in other studies that are conducted within a fairly homogeneous region, where recreation supply is relatively fixed, and the recreation experience can be clearly defined.

Cicchetti *et al.* (1969) added considerably to the methodological framework of forecasting recreation consumption. They include both socioeconomic population characteristics and supply factors in their model. The general form of the model is:

$$y_{it} = f(\text{distance at } t - 1) + f(\text{quality and quantity at } t - 1) + f(\text{socioeconomic characteristics at } t)$$

where  $y_{it}$  = expected quantity of a particular type of outdoor recreation consumed by the  $i^{\text{th}}$  individual in time period  $t$  (current time period).

Distance at  $t - 1$  = the physical distance between the location of the  $i^{\text{th}}$  individual and recreation facility in period  $t - 1$ .

Quality and quantity at  $t - 1$  = measures to reflect the relative availability of recreation facilities in period  $t - 1$ . Quality was measured by an index of crowding; quantity was indicated by water availability and the acreage of recreation land available.

Socioeconomic characteristics at time  $t$  = the characteristics of the  $i^{\text{th}}$  individual in time period  $t$ .

The use of lagged variables was based on the assumption that some determinants of recreation behavior in period  $t$  actually had their impact in the period  $t - 1$ , the previous period. Cicchetti *et al.* (1969) suggest that learning by doing (e.g., the tendency for people to fish more once they have fished), communications (e.g., learning about new fishing areas), and past recreation habits are determinants of behavior that should be included as time-lagged variables in predictive models.

An additional methodological refinement used by Cicchetti *et al.* (1969) was the use of a two-step procedure to forecast recreation consumption. The first step consists of developing an equation to predict the probability of an individual's choosing to participate in a particular recreation activity. The second step estimates the amount of the activity in which he is likely to participate. The two-step procedure represents a refinement in model construction since it begins to incorporate the decision process of the consumer. The two-step model was based on the assumption that different variables would interact to determine, first, whether or not a person is likely to participate in an activity, and second, how much he is likely to participate.

A further modification offered by Cicchetti *et al.* (1969) was to deflate recreation supply variables on a per capita basis, rather than use absolute

quantity measurements. Deflated supply variables reflect the relative, rather than absolute, recreation supply available to a particular population.

Even with the innovative changes introduced to refine existing techniques, results of the Cicchetti studies were disappointing. For the 24 recreation activities considered, the resulting models showed very low predictability. There are several possible reasons for this--not necessarily attributable to the Cicchetti model but to the method in general.

Even with the inclusion of supply variables, such models have usually resulted in low predictability. Part of the problem is the lack of precise regional population data. But data collection is expensive and model construction is often tied directly to constraints imposed by data contained in the U.S. population census. The relationship between predictor variables is difficult to determine; e.g., the individual "net" effect of causal variables on recreation participation.

All such models are static in that they assume that the observed relationships between predictor variables and recreation consumption will remain constant to the projection year. Finally, most models that predict recreation consumption are based on socioeconomic variables that reflect past recreation behavior. Projecting the predictor variables to some future date is, in and of itself, likely to introduce considerable error into consumption forecasts.

Although progress has been made, a further restriction is that the models seldom include the influence of changes in facility supply on consumption. Most often, such models contain the implicit assumption that a constant relationship will exist between the mix of recreation facilities available now and the mix of facilities available during the prediction year.

Although the approach has inherent limitations, it provides a basic framework on which to develop comprehensive recreation forecasting models that are suitable for long-run resource decision-making purposes.

#### Demand for a Specific Resource

Consumption models for a specific resource have been developed in response to

a need for on-the-ground planning information. Many of the techniques described in the previous section have application to forecasting consumption for a specific resource. The main difference between regional models and models for a specific resource is in the scope of the model and the way in which data are collected. Data collected through national user surveys are of little value in developing models to forecast recreation consumption for a particular resource.

Although it is often done in regional forecasts, it is incorrect to assume that all recreation areas that provide facilities for a particular activity will receive an identical proportion of use. There are several reasons why facilities do not receive similar use intensity. The amount of recreation consumed differs between areas depending on characteristics of the population served, climatic variation, and relative transportation availability. Different recreation areas vary in attractiveness. Finally, the supply of substitutable recreation facilities within a particular region will influence consumption at individual facilities within that region.

Models that forecast use for specific recreation facilities fall into three categories: resource capacity, supply characteristics, and gravity models.

### Resource Capacity

The saturation or resource capacity approach is often used to establish absolute upper limits on the amount of recreation that an area can sustain, or on the amount of physical resource that can be developed for recreational purposes.

The saturation approach is based on the assumption that upper limits to recreation consumption are imposed by sheer numbers of people who want to engage in a particular recreation activity, for which resources are fixed. The approach assumes a finite resource and an effectively infinite recreation demand. Under the assumption of infinite demand, forecasts of recreation consumption are simply not needed. The approach assumes that increasing recreation consumption can only be met by resource development up to a certain point. After the maximum is reached, resource deterioration will occur because of the excessive number of users. When this occurs, equitable management control systems need to be established to

allocate use in order to maintain the basic resource integrity.

Recreation development planning based on resource capacity usually begins by inventorying the resource to determine its physical development potential. Once carrying capacities are established, resources are developed and use pressure is kept within resource capability limits. Use controls would then be initiated to maintain the resource.

The saturation principle and resource limits approaches have merit when the recreation resource of concern is relatively fixed. Some National Parks, where consumption levels exceed carrying capacity, provide examples (Conservation Foundation 1972). In such instances, the decisionmaker would benefit very little by knowing that if he *could* expand available supply, recreation consumption *would* increase to some estimated level.

At least for the immediate future, the saturation or resource limits approaches to planning do not provide the flexibility needed for the majority of recreation planning decisions. In most planning situations, resource capability is not fixed and demand is not infinite.

### Supply Characteristics

A number of models have been developed to determine relationships between use intensity and physical characteristics of recreation facilities. The mathematical models describe the relationship between physical characteristics and recreation use over a season, peak-use period, etc. Distances between recreation areas and population centers are often included as variables in supply models.

An example of the supply approach is a regression model developed by Shafer and Thompson (1968). The model takes the form:

$$U = 3409 - 0.0183 X_1 + 0.1757 X_2 (X_3 \cdot X_2^2)$$

where:  $U$  = number of groups visiting an Adirondack campground per year.

$X_1$  = total square feet of land and water area at the campground swimming beach.

$X_2$  = total number of campsites in the campground.

$X_3$  = total number of islands accessible by motorboat from the campground.

This model accounted for 98 percent of the variation in seasonal use among the 24 Adirondack campgrounds studied. The site variables can be easily measured for any one campground and plugged into the equation to provide an estimate of annual use.

Using a similar approach, Seneca and Cicchetti (1969) developed a model that accounted for 74 percent of the variation in the number of visits to 154 recreation sites located in the Appalachian Region. The variables included in their equation were several supply characteristics of the recreation sites and whether or not a user fee was charged. Another example of the supply approach to forecasting recreation use is a model developed by Echelberger and Shafer (1970) which estimates the use of 26 ski areas in the Northeast from three site variables plus a distance measurement. The model explained 71 percent of the variation in total visitor-days among the ski areas.

Predictive models based on supply features usually account for a high proportion of past recreation use. A major limitation to supply models, however, is that they correlate past use to past supply features. The models explain what happened in the past, but are of limited value in determining what is likely to happen in the future. Examination of the predictor variables used in supply models usually shows that the size of a recreation area, in terms of facility units, is strongly correlated with recreation use. The obvious conclusion is that the bigger an area, the more use it has received. The relationship reveals little about predicting consumption, but merely implies that an increase in supply will result in an increase in consumption.

Supply models can be used to explain why some recreation sites are more heavily used than others. But they are of limited value in forecasting overall recreation consumption. This is particularly true for new recreation facilities. But past research has shown that supply characteristics are important determinants of con-

sumption and they must be included in comprehensive forecasting models.

### Gravity Models

The gravity model is an attempt to establish a mathematical relationship between the relative location of population masses and frequency of visits to a given recreation facility or group of facilities. The basic extension of the gravity concept to recreation facilities was proposed by Hotelling (1947) and Trice and Wood (1958), and further developed by Clawson (1959). The gravity model evaluates the use of an area or areas as a function of distance in miles or time traveled from a population center or centers to the recreation area. The model simply stipulates that as distance to a recreation area increases, the use of the area decreases according to some mathematical function.

Adaptations of gravity models have been used in three ways: by Clawson (1959) and Cesario (1969) as an approach to evaluating economic demand (price/quantity) for a particular resource; as a way of relating distance to recreation use (Smith and Kavanagh 1969); and as a component of larger models that combine socioeconomic user characteristics, resource supply features, and distance to allocate recreation consumption.

Various approaches have been taken to quantify the monetary value of a recreation resource. The basic approach suggested by Hotelling has been extended by Clawson (1959). Clawson's procedure involves two steps. First, a demand curve is constructed for the entire recreation experience. The distance traveled from various zones surrounding a recreation resource is used as an index to cost. The method assumes that distance is the major cost under conditions where a recreation experience is priced at a near zero level. A schedule or table is derived that relates the number of people visiting a recreation area per 1,000 base population within a distance zone to travel cost per visit per party. Under the assumption that increases in unit admission price will influence consumption equally across distance zones, the second step consists of constructing an economic demand curve for the recreation experience. Clawson's basic gravity relationship has been fur-

ther refined to approach the difficult problem of deriving economic demand curves for outdoor recreation (Knetsch 1963, Ullman and Volk 1962, Merewitz 1966).

The gravity model has been used in numerous studies to relate use of a particular recreation site to distance traveled to the site. Smith and Kavanagh (1969) used the gravity relationship to construct a reliable model that described the number of visits to a 1,570-acre reservoir in England per 10,000 population residing in urban areas within an 80-mile radius. The model provides estimates of use emanating from urban and rural population density zones as a function of distance from the reservoir.

Wennergren and Neilsen (1968) determined the relationship between the number of boating trips taken by a sample of 9.2 percent of the boaters in two northern Utah counties and the travel distance between a respondent's residence and a particular lake. Their equation explained 80 percent of the variation in the probability that a given recreationist would visit any one of 22 alternative water recreation sites.

Several problems are encountered in applying the simple gravity relationship directly to recreation consumption models. Although distance is certainly one of the major determinants of recreation behavior, it is but one of many factors that influence consumption. Alternative recreation facilities available to a given population should be incorporated in comprehensive models. Recreation site capabilities and development potential are usually not given adequate consideration. Perhaps the most important limitation to the gravity model is that dynamic changes within the population served, such as shifts in income and occupational structures, are not normally included as variables that will influence future recreation consumption.

### Systems Models

The systems approach to forecasting recreation consumption for a site, complex, or region, provides the flexibility needed to incorporate the many complex relationships that underlie the recreation consumption process. Large systems models can be used to generate consumption estimates and to allocate consumption between regions, or among

specific recreation sites within regions.

In general, the systems approach treats the recreation system as if it were an electrical circuit analog. Population centers act like sources of current (potential consumption). This current flows along paths of least resistance (highways), and eventually reaches its destination (recreation sites). A systems model should specify the interrelationships between all operating components. It should describe how wildland recreation resources, facility supply, and the recreational needs and interests of people interact to produce "effective" recreation consumption patterns. The system should be flexible so that management and policy alternatives can be introduced to determine their effects on the operation of the system.

The process used to develop a systems model includes: definition of system limits--parameters and major components (geographical area, recreation activities of concern, relevant population, etc.); identification and mathematical description of system components; computerized representation of the system; and system modification to conform to observed recreation behavior patterns. Once the model is operational, parameters can be manipulated to determine their effects on system operation and recreation consumption patterns.

The gravity relationship has been applied to recreation systems models in numerous studies (Cesario 1969, Wennergren and Neilsen 1968). The basic formulation involves determination of recreation pressure emanating from user origin areas, and then allocating the recreation pressure among recreation destinations. The distance between origin and destination acts as a resistance to flow along an origin-destination link. Link resistance can be measured by highway distance, road quality, travel time, travel cost, or some combination of these measures. The resistance due to distance can be adjusted to reflect the drawing power or attraction of a particular recreation destination. Attraction indices for recreation sites reflect their relative desirability for a particular activity.

The Recreation System (RECSYS) model developed by Ellis (1966 Part I and II, and 1967) and Chubb (1967) was among the first application of a systems model to comprehensive recreation planning. The

RECSYS formulation was initially developed for application to 12 major recreation activity groups. Because of the scarcity of recreation activity data, the model was developed and applied to boating activity in Michigan. The RECSYS model allocates boating activity originating within 68 Michigan counties or pairs of counties and six out-of-State areas to 72 counties or pairs of counties within the State.

Boating demand pressure is assumed to act through nodes located within origin areas or through major entrance points for out-of-State boaters. Destination nodes, the points through which user pressure is dissipated, are designated as the geographic center of boating resources for each destination area. Origin nodes are connected to destination nodes by highway links. Distance, tolls and travel time are used to compute travel resistance along each origin-destination link.

To bring resource supply into the system, a boat use capacity index is calculated for each destination. A subjective system is used to develop attraction indices for destinations. Included in the destination attraction indices are factors such as lake size, fishing potential, and percentage of warm water lakes.

Base year data from a 1966 Michigan Waterways Commission boating needs survey were used to construct the initial RECSYS model. The survey data provided information on the origins of registered boaters, as well as the counties in which they boated, and the amount of boating done at destinations. The sample data were expanded in proportion to the total number of registered boaters within each origin zone and calculations were made to determine the total amount of boat use generated at each origin and used at each destination.

Once the data were compiled, the computerized model was run, and results compared to actual observed boater behavior. Components of the model (destination attraction indices, highway link costs, and highway trip distance) were reevaluated, and the model calibrated or mathematically adjusted to fit observed boating behavior.

Once the model is calibrated, changes in highway links or other model components can be projected to produce future data. Supply adjustments can also be introduced

for the projection year to reflect facility construction and resultant changes in attraction indices at destination nodes. These projected changes in model components can be tried to determine their effects on the operation of the system. Once parameter estimates of the model are projected to some desired year, the RECSYS model can be used to forecast recreation consumption at destination areas. A mapping technique has been coupled to the system so that supply requirements or deficiencies can be easily identified. As better input data become available, the RECSYS model can be improved (Recreation Research Consultants 1972).

Another extension of the systems approach to forecasting recreation use is the transportation analysis system being developed for national forest planning. The basic model has been developed by the Institute for Transportation and Traffic Engineering (1971) at the University of California, in Berkeley. The recreation systems model is one of several transportation models under development.

The Institute for Transportation and Traffic Engineering (ITTE) recreation model is made up of several submodels. The two basic types of models are: macromodels that generate and distribute recreation consumption from major urban areas in California to National Forests in California; and micromodels that distribute trips among recreation facilities within a particular National Forest. Both the macromodel and the micromodel incorporate an attraction model used as an index to the relative drawing power of a forest or developed recreation site within a forest. The attraction models are used to compute an attraction index based on recreation-related characteristics of a particular forest or a recreation site within a forest.

Like the RECSYS model, the ITTE model requires base year inventory data to calibrate the initial system. Inventory input data include physical measures of regional and forest transportation systems, forest resources, facility characteristics, and characteristics of people living in population centers that interact with a forest. Recreation activity data include the type, amount, and kind of recreation use, as well as the origins and destinations of recreation users. Travel patterns and preferences within and between

forests must be determined through recreation user surveys.

The three components of the macro-models are population centers (population origins), transportation impedance (highway travel time, cost, and distance), and forest attractors. Forest macroattraction models are developed using three factors that relate to water, land resources, and recreation facilities available. Micro-model components are similar, except that the attractor model is developed for specific sites within a forest. Micro-attraction models for individual sites are determined for each recreation activity of concern; e.g., fishing, camping, and swimming.

The macrogeneration model utilizes population size, county income, age distribution, and National Forest accessibility to estimate mathematically the recreation pressure emanating from a particular population origin zone. It estimates the quantity of trips generated at origins, regardless of where the trips are distributed.

Although still relatively new, the systems approach provides the most comprehensive method for forecasting and distributing recreation within and among recreation resources. But as Cesario (1969, p. 42) points out, in general the systems approach,

"...suffers from the same problems of other methods in that the variables have been measured and each component modeled before the analysis can proceed. In addition, the assumption of a linear system is restrictive. Since each travel link is modeled separately, the model does offer the strong possibility of introducing peak congestion into the analysis--something that has not been accomplished with other models."

In addition to the conceptual problems involved in building systems models, the approach relies heavily on resource supply and recreation use data. The precision to which the model can be developed depends on the size of the geographic unit from which data are collected; i.e., State, county, or local level. A computer is necessary and specialized personnel are required for initial model construction.

Although the systems model is complex and has heavy data requirements, it is comprehensive and all relevant components that influence recreation behavior can be includ-

ed. As recreation supply and recreation inventory data become available, the systems model will undoubtedly become a valuable planning and decisionmaking tool.

## DEFICIENCIES OF ALL METHODS

All methods used to forecast recreation consumption have inherent deficiencies. Some methods are better for specific purposes than others. Two important factors that are seldom adequately considered in forecasting models are the quality of recreation experience associated with a particular level of recreation consumption and the impact of technological developments on future consumption patterns. Few models inherently recognize the role that management can play in influencing consumption.

A reliable forecast of expected recreation consumption will provide managers with needed planning information. An ideal method would recognize the trade-off relationships that exist between quantity of recreation consumed and quality of recreation experience received. The influence of the quality of experience on quantity consumed is implied in some of the systems approaches via attractiveness indices for specific recreation resources. Most attraction indices, however, are based on physical features of the resource, not necessarily on the quality of experience received.

More research is needed before the qualitative aspects of recreation experiences can be incorporated into recreation forecasting models. Some research attention has been devoted to the study of qualitative aspects of recreation experiences and environments. For example, in a study aimed at developing a system for rating natural landscapes, Shafer *et al.* (1969) developed a model that explained 66 percent of the variation in preference scores for a wide range of natural environments described by black and white photographs. A similar study by Peterson and Neumann (1969) utilized a psychological testing instrument (semantic differential) to develop a model that explained 94 to 98 percent of the variation in preference scores for Chicago area beaches. Other examples of studies designed to measure intangibles are those by Lansing and Marans (1969), Kasmar (1970), and Neulinger and Breit (1969). But little quantitative research

has been conducted into recreation motivations, expectations, and satisfaction received.

Most approaches to forecasting recreation consumption do not incorporate the dynamic changes of technological impacts on recreation behavior. Technology will have a major impact on recreation behavior through changes in equipment design, environmental management, and environmental control systems. Predictive models should be sufficiently flexible so that relevant parameters can be altered as new technological developments are introduced.

Finally, recreation consumption models need to incorporate the role that management and policy play in influencing consumption. Most models implicitly assume that the interaction between managers, recreation users, and resources will be constant through time. In the past, management has largely reacted to recreation pressures, rather than acting to meet or influence these pressures. As indicated in the Conservation Foundation's Report to the National Park Service (1972), recreation management policy must play an increasingly important role in influencing recreation behavior in the future.

### CONCLUSIONS

Planning must rely on forecasts no matter how imperfect the forecasts may be. All of the methods used to forecast recreation consumption, from the simplest trend extrapolation to the most complex systems model, have been found lacking in some respect. Yet much progress has been made in a short time toward providing needed estimates. Advances in computer technology, coupled with better data collection systems and more intensive research into the processes that determine recreation behavior, will undoubtedly allow more precise forecasting models to be developed in the future.

Yet we must not be overly optimistic. Prediction in social systems is at present more an art than a science. The essence of the problem was underscored by Kenneth Boulding when he cautioned (Rosenberg 1971):

"The careful planner if he can  
Should always plot to change his plan;  
And if he follows sound directions  
Will not believe in his projections  
For population growth depends  
On many contradictory trends,

Though sex can be predicted (maybe!)  
We're much less certain of the baby

...

"The future, then, is most uncertain,  
And lies behind a heavy curtain.  
It's bound to have some kind of strings,  
So let's prepare for lots of things  
(Especially to switch and swerve)  
And not hitch wagons to a curve."

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# LOCATING AND DESIGNING CAMPGROUNDS TO PROVIDE A FULL RANGE OF CAMPING OPPORTUNITIES

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**ABSTRACT.**--Discusses the location and design principles of campgrounds accessible by automobile including: (1) the need for variety within a region, (2) the kinds of campgrounds and where to locate them, (3) the role of private and public campground managers, (4) the role of design in reducing physical resource deterioration, and (5) the role of location and design in enhancing the experiences of campers.

## THE PROBLEM

Today, demands for recreation facilities are great, suitable land is often scarce, and land management decisions are being contested by a variety of publics. Planning decisions must, therefore, be carefully made with a clear understanding of the interrelations of people, physical resources, location, and design. To achieve good location and design of campgrounds, a recreation manager must carefully evaluate the relative merits of alternative locations and different kinds of campgrounds.

Poorly located and poorly designed campgrounds can be a millstone around the neck of the recreation manager. The private operator can lose his entire investment; public agencies pretty much have to live with their mistakes. Construction costs per family unit in Forest Service campgrounds, for instance, range from \$2,000 to \$5,000.<sup>1</sup> Once construction begins, a decision to relocate the facility or make drastic changes in the design of facilities is probably too late.

Considerable research suggests that many campgrounds are not doing the job intended, in some cases because of poor location and design. Some campgrounds go practically unused (Burch 1964; Love 1964; Lucas 1964, 1970; Beardsley 1967; Shafer and Thompson 1968; Shafer 1969; Lime 1971). Many private campgrounds have difficulty showing an adequate return on their investment (LaPage 1967, LaPage *et al.* 1972). Poor location and design sometimes cause wide variations in the use of campsites *within* campgrounds (Love 1964, Lime 1971).

My purpose is to discuss the location and design principles of developed campgrounds (those accessible by automobile) particularly on public forests. The paper is divided into (1) the need for variety within a region, (2) the kinds of campgrounds and where to locate them, (3) the role of private and public campground managers, (4) the role of campground design in reducing physical resource deterioration, and (5) the role of location and design in enhancing the experiences of campers.

## NEEDED: A VARIETY OF CAMPGROUNDS REGIONALLY

Traditionally, campgrounds have been viewed by many recreation managers as a means of "controlling" visitors to insure the protection of the natural environment. Concentrating people in a small area also has enabled more efficient law enforcement and fire control. As demand for campgrounds grew, new facilities often were immediately built or existing areas modernized or enlarged, to "handle" visitors as efficiently and as cheaply as possible. Additional campsites were often built between existing sites with little regard for the satisfaction of campers. Consequently, many small, informal campgrounds have been replaced by large, modern, intensively developed campgrounds. This and other changes in the layout and design can greatly alter the values derived by present campers. The process of "creeping" campground development forces out a sizable segment of the camping population that is seeking solitude and contact with nature (Hendee and Campbell 1969). In many areas these "displaced campers" can no longer find the small, primitive campgrounds that they enjoy.

To meet these demands for campgrounds, standardized facilities have often been built in very dissimilar environmental set-

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<sup>1</sup>Includes road, water, sanitation facilities in addition to the campsite itself.

tings. The underlying rationale seems to have been that "campers are campers," and they will use *and like* whatever is provided for them--supply creates its own demand (Lime 1972). This thinking is evident in the numerous space standards reviewed in "Outdoor Recreation Space Standards" (Dep. Inter. 1967). Despite the wide range of standards, most were developed from intuitive judgments and trial and error rather than from research (Lime and Stankey 1971).

In reviewing nearly 100 studies of campground use and visitor attitudes, I concluded that trying to provide facilities that are thought to satisfy the "average" camper contradicts the major objective of outdoor recreation management. This objective is to provide pleasing and rewarding experiences for all kinds of campers (within certain administrative, budgetary, and physical resource constraints, of course).

A growing body of research clearly demonstrates that the so-called "average" camper doesn't exist (Shafer 1969). Rather, many seemingly independent groups of campers exist, each with their own preferences for different kinds of camping (Bury 1964; Burch 1964, 1965; Green and Wadsworth 1966; Bultena and Klessig 1969; West *et al.* 1969; Moncrief 1970; Clark *et al.* 1971; Hendee *et al.* 1971; Taylor and Knudson 1972; Merriam *et al.* 1973).

Several authors have emphasized that while traditionally camping had an environmental orientation for participants, more recently camping has become much more of a social experience (Etzkorn 1964, Bultena and Klessig 1969, Hendee and Campbell 1969, Clark *et al.* 1971). Even the most casual observer is aware of the resulting trend toward convenience and "creature comforts" in camping. Paraphernalia used by campers is more sophisticated. Many campground franchises have become potential "camping resorts" such as Holiday Inn Trav-L-Parks, Kampgrounds of America (KOA), and Jellystone Parks. This evolution in campgrounds has led to an increasingly diverse camping population with varied and often conflicting desires, and it has important implications for the location and design of campgrounds.

Because of the diverse benefits being sought by campers, planners should provide a wide spectrum of camping opportunities within a given geographic area (Wagar 1966). There is an obvious need for collaboration among the various private and public campground managers to make sure a full range of opportunities exist (Burch 1964, Kru-

tilla 1967, Goldin 1972). No one manager need feel obligated to meet the demands of all campers, however. Each public agency, for instance, could meet a part of the demand, and refer campers wanting something different to another campground (Lucas 1963). Progress is being made through long- and short-term management plans, but more coordination is both necessary and desirable.<sup>2</sup>

Efforts by recreation managers to insure a range of camping opportunities in a region must be matched by effective publicity to inform potential campers where the various types of campgrounds are. Many imaginative techniques to communicate with recreationists are possible, such as visitor information centers in metropolitan areas and greater use of radio and television. Communication can also serve to educate recreationists in basic outdoor values, ecological concepts, and management policies.

#### WHAT KINDS OF CAMPGROUNDS AND WHERE TO LOCATE THEM

A decade ago Alan Wagar (1963) developed a useful classification of campgrounds needed to serve different purposes. Five of the seven types he identified are campgrounds accessible by automobile: (1) travelers' camps, (2) central camps, (3) forest camps, (4) peak-load camps, and (5) long-term camps. More appropriate terms for central camps and forest camps might be "social- and environment-oriented campgrounds." These terms will be used hereafter.

Each type of campground has distinctive location and design criteria. The relative level of development and accessibility can be graphed for each type (fig. 1). Generally, *elaborate* campgrounds have flush toilets, sewer and water hookups, electricity, a store, and other conveniences. These campgrounds usually have many family units with little space between units. Conversely, *simple* campgrounds typically have only vault toilets and well water; family units are few and widely spaced. Admittedly, a small campground could have elaborate facilities (flush

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<sup>2</sup>Recent communications with State campground planners in Michigan, Minnesota, and Wisconsin indicate some public agencies are defining the type of campgrounds they will provide. They realize that the private sector has to meet the specialized needs of a different portion of the camping population.

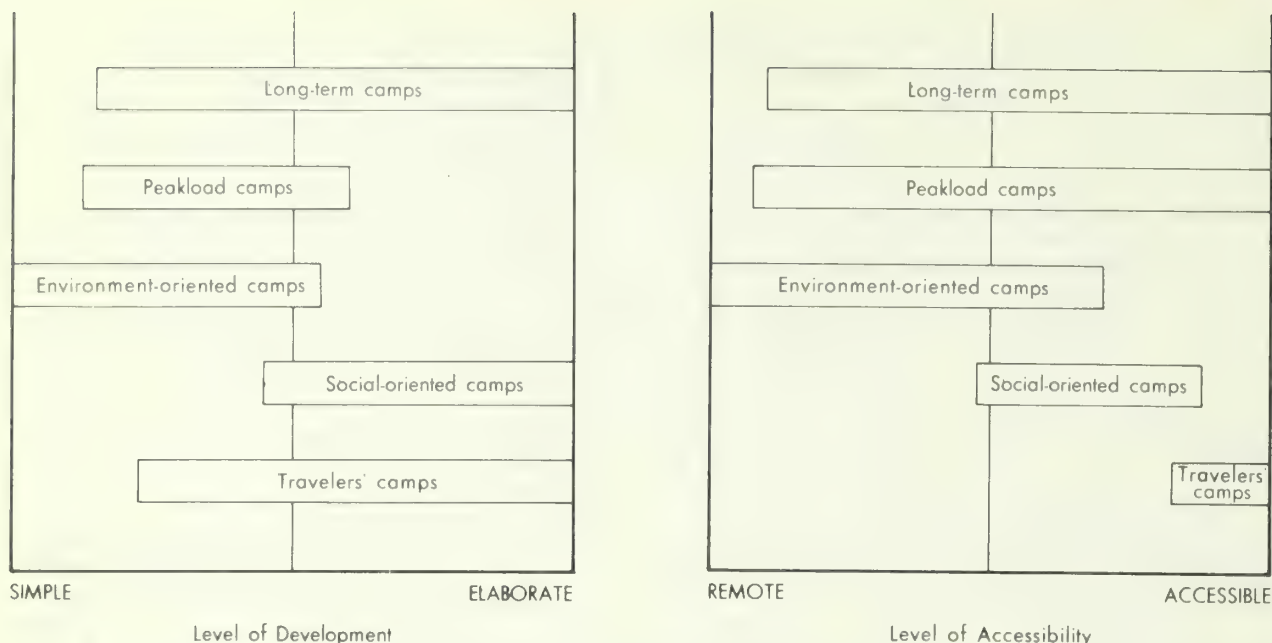


Figure 1.--Relative level of development and accessibility of five types of campgrounds. (The terms "simple" and "elaborate" denote a range in character and number of facilities.)

toilets and electricity) and widely spaced family units. Its relative position on the continuum of development in figure 1 would be intermediate, however.

No attempt is made in this paper to identify the relative supply or demand for the various types. It is assumed, however, that a mix of campgrounds is needed now and will continue to be needed in the future.

#### The Travelers' Campground or Open-air Motel

Travelers' campgrounds emphasize convenience for the transient camper and are generally located near main highways in pleasant settings. They should be distributed throughout a region not only in rural areas but also near (or perhaps *in*) large and small urban areas. A review of several commercial campground directories showed that very few campgrounds now exist in or near some large metropolitan areas. Only two campgrounds (totaling 28 family units) are located within 20 miles of downtown Milwaukee and only one campground (11 units) is within 20 miles of the Chicago Loop (Rand McNally and Company 1973).

Most travelers' campgrounds are elaborate and have flush toilets, electricity,

showers, laundry facilities, a grocery, and other conveniences associated with motels. There undoubtedly is some demand, however, for a variety of simpler travelers' campgrounds as well. Perhaps some travelers' campgrounds could be imaginatively designed for those who want both access to conveniences and isolation in natural surroundings. A modernized section could have peripheral campsites with simple facilities, wide spacing, and vegetative screening. These campsites could also provide accommodations when the modern section was full.

#### The Social-Oriented Campground

Social-oriented campgrounds would attract weekend or vacationing campers rather than transients. Campgrounds would be located in pleasant surroundings several miles from main highways, and would be reached by high speed rather than secondary roads. Social-oriented campgrounds should be located on the fringe of large areas of public land, rather than in the interior. Their location should be intermediate--not accessible enough to attract transients, but not so remote as to conflict with campers seeking isolation and communion with nature. Ideally, they should be distributed in all parts of a region.

Campgrounds would be intensively developed with conveniences like electricity, flush toilets, showers, sewer and water hookups, laundry, and store. Imaginative facilities such as playgrounds, riding stables, and boat rentals also serve to attract customers. Obviously, numerous levels of development are possible and desirable. These campgrounds typically would be large (with more than 50 campsites to several hundred) and spacing between units would be close to enhance interest in socializing among campers (Etzkorn 1964).

### The Environment-Oriented Campground

Because visitors to these campgrounds want direct contact with nature, environment-oriented campgrounds should be located farther from main highways and near highly valued recreational attractions like trails, outstanding vistas, unique landforms, water features, vegetation communities, and geologic formations. Low speed (perhaps gravel) roads could be the only access for many of these campgrounds to "screen out" those campers not truly nature-oriented. In large areas of public land, the interior would be used for various environment-oriented campgrounds without intensive development (Hendee and Campbell 1969, Clark *et al.* 1971).

These campgrounds would have fewer campsites than the previous kind, usually less than 20 and never more than 50. Campsites would be moderately shaded and well screened with vegetation to insure privacy. Spacing would be wide, from 100 to 200 feet; some sites might be walk-in units and separated by 400 to 500 feet. To satisfy divergent tastes, some campgrounds should be very remote, small, and simple with only vault toilets and well water; others could combine a remote location with moderate development (e.g., running water). Research findings have consistently shown that campground design should be varied (Lucas 1970, Lime 1971).

### The Peak-Load Campground

When campgrounds exceed their designated capacity on holidays and opening day of fishing or hunting season, temporary or peak-load facilities are required. Provision for peak-load camping should be considered in the planning and design stages of all campgrounds. Some campsites could be left semifinished (excluding barriers, walkways, toilets, tables, and hand pump or water system hookups) to serve as overflow

areas and a means for measuring the need for additional campground units before large sums of money are further invested.

Similar reasoning could be employed in developing temporary hunting and fishing camps in locations away from existing campgrounds. A campground access road with a small loop or cul-de-sac and perhaps parking spurs would be required. The road could be blocked and visitors excluded when the area is not needed. Camping areas of this type might also serve well the needs of large groups, organizational parties, and persons on field trips. As regional demand increases, some peak-load camping areas could be turned into full-time campgrounds.

In campgrounds that are already developed, overflow camping can be provided in adjacent meadows or clearings where wide spacing between sites can partially make up for a lack of screening vegetation. Facilities such as toilets, tables, and drinking water systems should be kept simple and portable if possible.

### The Long-Term Campground

These campgrounds serve the minority of the camping population who prefers to either leave their equipment at one place and repeatedly return to "their campsite" perhaps on weekends, or stays for a month or so at a time in the same location. This type of campground typically would not serve travelers, but travelers' campgrounds might have some campsites for long-term users.

Long-term campgrounds could have characteristics of either social- or environment-oriented camps, but I suspect most long-term campers are socially oriented and most demand would be for intensively developed campgrounds.

On public lands, long-term campgrounds should not compete for land needed for other types of campgrounds. If competition develops, long-term campgrounds should be phased out and converted to social- or environment-oriented campgrounds, depending on the level of development and location.

### THE ROLE OF PRIVATE AND PUBLIC CAMPGROUND MANAGERS: WHO SHOULD PROVIDE WHAT

In a recent paper Angus, Corssmit, and Foster (1971) presented a conceptional framework for providing various kinds of developed campgrounds by private and public managers. Their basic thesis is that "... when the private and public sectors can do an equally satisfactory job of supplying facilities, private supply is preferable." They empha-

size that public campground managers may need to stimulate the supply of facilities during the early stages of the growth of the market, but should stop further development when the private sector responds to increasing demand.

In the past, the public sector has supplied the bulk of America's developed campgrounds. More recently there has been a large expansion in the number of camping areas provided by private industry. One writer notes that during the past few years, the number of private campgrounds has grown at the rate of some 2,000 annually (DeMattis 1973). In Minnesota, for instance, in the early 1960's, there were fewer than 10 private campgrounds; today there are nearly 400. This suggests that it is a good time for public agencies to reevaluate their roles in providing developed campgrounds.

In cases where the private sector does not show an ability or interest in providing campgrounds, public agencies may have to provide them. It is my observation in the Lake States, for example, that the private sector has not responded to people desiring primitive, environment-oriented campgrounds. If more campers were to seek primitive outdoor experiences in the future, the interests of businessmen could change (Krutilla 1967, Hendee 1969, Burch and Wenger 1967).<sup>3</sup>

Careful collaboration among public and private campground managers can insure a full range of camping opportunities within a region. It is suggested that the various public agencies and the private sector could each provide campgrounds of a certain level of development; all together they would provide the whole range of campgrounds from simple to elaborate (fig. 2). Federal agencies, for instance, would have a major role in providing low-density, simple campground development. In some cases they might provide a few intensively developed camping areas where private campgrounds do not yet exist and where profitability is questionable.

Who should provide the five types of campgrounds identified earlier, public or private managers?

Travelers' campgrounds should be operated largely by private owners on private

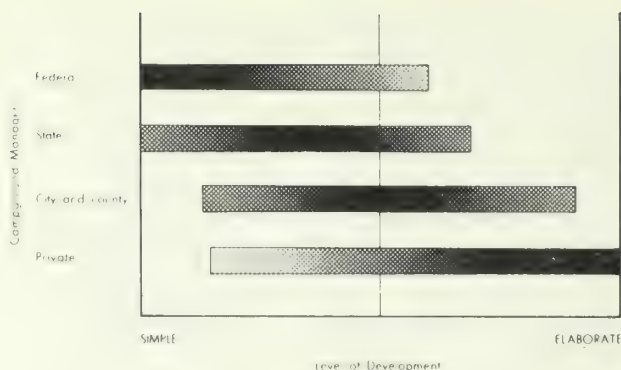


Figure 2.--Suggested levels of development for public and private campground managers. (Densely shaded part of bar represents level of development most managers should provide.)

lands, or by concessionaires under special use permits on public land. This pattern develops naturally in areas of little public land. In areas of extensive public holdings, however, public managers should seek out and encourage private development on adjacent private lands, or least suitable public land on the periphery to private managers.

Social-oriented campgrounds generally should be operated by private entrepreneurs rather than by public agencies. However, in areas where the private sector shows no interest in responding to a demand for elaborate campgrounds, the public sector has the responsibility to provide them. As circumstances change, the public facilities could be leased to an interested private manager under a special use permit, thus avoiding competition between the public and private sectors.

Because of their interior location in a public forest area, environment-oriented campgrounds most likely would be operated by the public agency rather than by a concessionaire (although concessionaires might be appropriate in locations nearer the periphery of the public land). If the private sector demonstrates an ability and interest in providing these more primitive camping areas, the public agency should work with them to provide a variety of campgrounds in the region.

Peak-load campgrounds might be operated by either public or private managers. Private campgrounds might well have an overflow area adjacent to existing campsites, but it would seem unlikely that peak-load camping as a business would be very profitable. Some resort and restaurant operators and other

<sup>3</sup>Some believe that persons initiated to car camping at an early age (in intensively developed camping areas, for instance) may seek more primitive developed campgrounds as well as wilderness as they become older.

merchants with sufficient land located in prime tourist areas might be able to supplement their incomes by providing temporary campgrounds.

Long-term campgrounds probably should be operated by owners of private lands or by concessionaires on public lands because these camping areas give exclusive use to a few campers. This type of business venture might be appealing because of the more predictable income it could provide.

#### THE ROLE OF CAMPGROUND DESIGN IN REDUCING THE DETERIORATION OF PHYSICAL RESOURCES

Management can use several techniques to protect soil, vegetation, wildlife, and water in and around a campground: proper location of roads and trails, proper placement of facilities, channeling pedestrians and vehicles, hardening trails and roads, fertilization, reseeding, and rotation of use.

Meinecke (1932, 1934) long ago recognized the importance of properly locating roads and facilities in campgrounds, as did Taylor and Hansen (1934). These observers recognized the campsite and parking area as an integral unit and gave advantages of both the pull-through and dead-end parking spurs. Although 40 years old, their writings are still timely and pertinent for designing campgrounds in the 1970's. I strongly recommend that planners read these articles.

These early observers also stressed the careful placement of tables, fireplaces, toilets, wells, pumps, and water hookups. For example, Meinecke identified the campfire area as a significant part of the camping experience, and articulated the importance of locating the fireplace so that prevailing winds assure good draft without driving smoke over the table and tent.

To protect onsite vegetation and reduce erosion, tent pads should be large enough to accommodate tents in common use today. A recent study in a Forest Service campground in Tennessee showed that 26 percent of the tent campers had tents larger than the pads (Cordell and Sykes 1969). Because more and more campers have screen houses and may bring two or more tents, planners should consider building more than one pad per campsite.

Damage to the campsite can also be minimized by providing some areas where two families or clubs can camp together on the same site. Group camping appears to be increasing, so planners should consider pro-

viding multiple-party sites on an experimental basis as part of their planning.

Proper channeling of pedestrians and vehicles helps to reduce wear on resources. Posts, logs, rocks, fences, and guardrails can be used to keep vehicles in parking spots and out of campsites (Magill 1970). Paths, elevated walkways, and bridges can similarly channel foot traffic. Pathways should not be selected arbitrarily, however. Routes that are picked simply because they happen to be the cheapest or easiest to locate probably will do little to enhance camper enjoyment and may not be used (Lime and Stankey 1971). Letting visitors choose their own routes around the campground and then hardening the paths with native stone, gravel, wood chips, or pavement is not always satisfactory either; an unnecessarily large amount of ground can be paved this way. More research is required on pedestrian traffic flow in campgrounds.

Ground cover and soil are commonly damaged by concentrated use (Stankey and Lime 1973). Fertilization, reseeding, and irrigation can help rehabilitate campgrounds. Prohibiting use of sites after fertilizing, for example, would permit worn campsites to recover. Campgrounds could be designed so that sites are rested 1 year in 3 (Lime and Stankey 1971). This could be done by constructing three distinct areas or loops with separate access roads and closing off a different one each year. During peak use, certain sites could be temporarily used. Admittedly, this would be costly and require expansion by at least one third; but, coupled with a continuing maintenance program, the results could be rewarding.

In summary, protecting the physical resource by good location and design is considerably more than making a few field observations, preparing maps, and then turning the construction and installation over to road engineers and others less sensitive to the delicate ecological and social consequences of construction. Good location and design must include even small details. For instance, a campsite might have a pleasant view of a lake, be well screened, and spaced far from other sites, but poor placement of the tent pad could cause excessive erosion--not to mention the dissatisfaction to campers during wet weather. Positioning the tent pad 5 or 10 feet one way or the other could make the difference between an eroded site and a stable one.

## THE ROLE OF CAMPGROUND LOCATION AND DESIGN IN ENHANCING VISITOR ENJOYMENT

Proper design and location not only helps protect the resource but also increases visitor enjoyment because most campers spend so much time at the campsite relaxing, cooking, and tidying up (Burch 1965, King 1966, Hendee and Campbell 1969). But how do visitors want campsites located and designed?

Many studies have been made in developed campgrounds to answer this question. Campers have been asked nearly everything from their opinions about the spacing between individual units to the design of fireplaces and grills (e.g., see Shafer and Burke 1965; LaPage 1967, 1968a; Cordell and Sykes 1969; James and Cordell 1970; Lucas 1970; Lime 1971; Cordell and James 1972).

Unfortunately the results of these studies are not often comparable because the studies have been conducted in dissimilar camping environments which attract people of varying tastes and environmental dispositions. Nevertheless, opinions and preferences of campers can be helpful in planning the kinds of campgrounds needed in a given area. Frequently, several alternatives are possible regarding the future development of camping areas, and knowing the opinions of visitors gives managers the basis for more viable and defensible decisions.

Space only permits discussing two aspects of campground location and design: (1) the placement of individual campsites with respect to water, and (2) the number of campsites in a campground--both of which are important to comprehensive recreation planning in the Lake States.

### Water-Oriented Campsites

Water is desirable both to look at and to play in and is the focal point of many recreational activities including camping. Water increases the attraction of both whole campgrounds and individual campsites as well (Burch 1964; LaPage 1967, 1968a; Shafer 1968; Lucas 1970; Moeller 1971; Lime 1971).

Opinions differ among many recreation planners regarding how individual campsites should be placed with respect to lakes and streams. Some argue that campsites should be kept well back from the shoreline to protect it. Others contend that since water is a focal point for visitors, campsites should be located close to it. Both positions seem valid. Therefore, a compromise appears possible in which the phys-

ical resource is protected and the preferences of campers are catered to as well.

Campsites should not be placed right on the lakeshore for several reasons. Trampling can eventually destroy shoreline vegetation and cause erosion that could even affect water quality. As a result, expensive retaining structures could be required to check further degradation. All of this destroys the shoreline scenery for both the visitors in the campground and those on the water. Furthermore, many recreation planners feel that the shoreline area should not be monopolized by the nearest campers, but should be equally available to *all*. It is argued that anyone should be able to walk along the shore without feeling like a trespasser.

On the other hand, there has been a recent trend on some National Forest campgrounds in the Lake States to place many individual campsites out of sight of the water. In some of the older campgrounds, some campsites are only 20 to 30 feet from the water; while in those built since 1960, many units are as far as 1,000 feet from the water. Moreover, in many of the recently expanded campgrounds the trend has been to place campsites away from the water, usually on the back side of a campground loop road.

This trend shows that some managers have little or no understanding of users' motives for visiting the area. A recent study in Minnesota showed that nearly all campers interviewed were very water conscious and many of them came to the woods in the first place to be near water (Lime 1971). To deny campers at least a view or glimpse of the water appears inconsistent with management's objective to provide campers with the experiences they seek.

The conflict between protecting the resource and satisfying campers could be solved in several ways. Campsites could be placed back from the shoreline 100 to 200 feet so as to still allow a view or sense of being reasonably close to the water body. Vegetation can be thinned, roads designed according to topography, and frequent, well-marked trails can be built to the shoreline (Burch 1964). But some shoreline vegetation should be left to act as a partial screen or buffer between campsite and water, and to protect the soil by dispersing use at the water's edge. Shoreline vegetation would also provide natural habitat for wildlife.

Interviews with Minnesota campers did not indicate that they wanted to be right on the shoreline (Lime 1971). Being back from the water 100 feet or so would probably be

very acceptable to people as long as the water was visible and breezes could penetrate the campsite. Moreover, some parents explained that they could better supervise small children if campsites were not too close to the water.

The possible additional costs of blending campsites into the landscape to make them truly water-oriented can be justified for several reasons. First, visitors will gain greater satisfaction from these preferred sites. Moreover, many visitors may be willing to pay extra for a waterfront campsite, as research in New England State Parks showed (LaPage 1968b). Furthermore, campsites "back in the woods," far from the water are likely to receive little use except to accommodate overflow. It is wasteful to have \$3,000 campsites sitting idle except for only 5 or 6 nights of use during an entire camping season.<sup>4</sup> A Minnesota study showed that waterfront sites averaged 60 percent occupancy compared to 25 percent for other sites (Lime 1971). Thus, waterfront campsites take the physical beating that the entire campground with its many units was originally designed to withstand. If all campsites were water-oriented, use would be more evenly dispersed and site deterioration would be reduced.

In summary, it is important for the resource manager to initiate a compromise in campground planning by preserving and protecting the shoreline as well as giving the visitor a sense of being close to the water.

### Campground Size

Researchers have found that most campers like a variety of different-sized campgrounds (Wagar 1963, Burch 1964, Burch and Wenger 1967, Lucas 1970, Lime 1971). In spite of this preference for variety, some public agencies in the Lake States have been constructing mostly larger camping areas--with a minimum of 20, 30, or more units. In some National Forests, for example, this trend has been coupled with the closure of many small, primitive campgrounds (most with fewer than 15 sites).

Those who advocate large campgrounds argue that construction, operation, and maintenance costs per unit decrease as the

size or number of units increases. Recent studies by Beardsley (1967) in Colorado and Manthy and Tucker (1972) in Michigan suggest that this argument is open to question and some rethinking may be in order. Beardsley, for instance, found that large facilities were not necessarily cheaper per unit to construct; factors such as the degree of rockiness or amount of earth moving required were considerably more influential. In the Lake States these factors could strongly influence cost. On the other hand, it was shown that campgrounds with more than 20 campsites were probably somewhat cheaper to operate and maintain. Although research on this topic is not extensive, available information suggests that campgrounds should be limited to 20 or 30 campsites, for example, until there is a definite need for more.

How can the costs of providing and maintaining large, medium, and small campgrounds within National or State Forests and State Park systems be reduced? One way would be to locate small campgrounds within 10 to 15 miles of larger facilities to reduce driving time during maintenance. Small campgrounds also could be located between collection points--between a ranger station and a large campground, for example. Moreover, appropriate sites that require only a short access road could be found for small campgrounds. Existing small facilities in relatively remote places are frequently classified as inefficient to maintain--especially those in which fees are collected. One solution to this problem would be a self-registration fee system. Minnesota has already initiated such a program in its State Forests. Lastly, the user satisfaction gained by providing a range of different-sized campgrounds might well outweigh the additional costs of operation and maintenance.

It would appear to be a mistake for any public agency to make campgrounds a standard size. The fact that many campers accept large facilities, provided they are well spaced and screened from neighbors, lends support to an apparent trend by some public agencies for larger camping areas and the phaseout of many medium and small facilities. Unfortunately, another sizable segment of the camper population needs and wants the small campgrounds.

### SUMMARY AND CONCLUSIONS

Although research on the use of campgrounds is somewhat scattered, much useful and reliable information is available to

<sup>4</sup>From a sample of 641 campsites on 33 campgrounds in the Superior National Forest, 39 percent were used less than 4 nights during the 35-day survey in 1967--12 percent were never used. This included Labor Day weekend (Lime 1971).

recreation planners. The following is a review of some general principles to help guide managers and planners in locating and designing campgrounds.

- The primary objective of campground management is to provide the experiences desired by campers.

- There is wide variation in the kinds of experience sought by campers who range from people interested mainly in socializing in the outdoors to those mainly interested in the environment.

- To provide for this range of tastes, there is a need for a wide spectrum of campgrounds within an area such as the Lake States.

- Campgrounds can be differentiated on the basis of their level of development and accessibility: travelers' campgrounds, social-oriented campgrounds, environment-oriented campgrounds, peak-load campgrounds, and long-term campgrounds.

- Ideally, each campground manager, public and private, would provide a certain type of campground so that a variety of different types would be available within an area.

- No one campground manager need feel obligated to provide the full range of campgrounds.

- The private sector should be encouraged to provide a variety of different types of campgrounds if it is interested and able. The public sector should be flexible enough to provide a variety of campgrounds, but should generally concentrate on the simpler or more primitive types.

- A variety of campgrounds within a region is not an end in itself. Publicity is needed so campers will know where to go to find the campground that suits their tastes.

In closing, I would like to suggest two ways in which recreation managers and researchers can cooperate in solving problems of campground location and design. One approach would be for managing agencies to invite qualified researchers with specific talents to consult with them directly during the planning, design, and construction of campgrounds. Assignments could last from several weeks to a year or more during which the participant might change residence.

Participants would need a high degree of objectivity and realize that some traditional ways of doing things might need to be changed. Exchanges would be fruitful to the maturity of researchers also. It would expose them to new problems of recreation management and planning, and could help them more clearly identify future research needs. Although there are probably few organizational constraints to this approach now, I know of only a few instances in which it has been done.

A second way would be for researchers and managers to conduct studies cooperatively in which imaginative campgrounds are planned, built, and rigorously tested to disclose both social and ecological consequences. For instance, studies could focus on: how campers perceive short walk-in or boat-to campsites from a central developed complex; various materials used in path and tent pad construction; different kinds of campfire units, grills, toilets, and tables; various amounts or kinds of vegetative screening between campsites or between campsites and nearby facilities; various distances between the parking spur and the remainder of the site facilities; various facilities such as swing sets, horseshoe pits, hiking trails, and all sorts of interpretive materials.

Both camper populations and campground characteristics could be controlled for careful analysis. In past research we have investigated simply what was available rather than a mix of what *could be*. All participants would have to be thoroughly committed to the effort, and realize that some designs and ideas would not prove successful. After a reasonable study time, the campground could be opened to ordinary public use.

The returns both to campers and managers from cooperative ventures such as these could far exceed the financial and administrative costs. Not only would the public find a greater number and more enjoyable mix of campgrounds, but managers would achieve a better distribution of use and be able to counter social and ecological problems more easily.

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## PHYSICAL SITE MANAGEMENT

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**ABSTRACT.**--Much information is available about the protection and maintenance of recreation sites, but the large number of resource variables and the highly specific nature of many research findings make it difficult to condense this information into a compendium of site management guidelines. Maximum use is apparently not being made of available site management information by recreation planners and managers. Reasons include the highly scattered nature of information, difficulty in obtaining pertinent material, and research findings not always directly applicable to the problem at hand. A proposal is made that site management information be computerized to provide periodic inclusion of new information and ready access of available material to all interested persons.

Recreational use of forest and wildland areas has grown quite rapidly and the rate of increase is expected to continue well into the future. From an estimated use of less than 10 million visitor-days on public lands in the late 1920's, it has grown to almost 450 million visitor-days in 1972. A further tripling of outdoor recreation demand by the year 2000 is forecast.

Such intensive use of forest and wildland areas for recreation creates overriding problems of how to make lands available to the public without impairing either the resource or the quality of the recreational experience. The ecological balance in forest and wildland environments is delicate, and where man returns frequently for prolonged periods of time, his direct impact on soils, vegetation, water, and forest beauty can be severe. Recreation site deterioration is a serious problem throughout the world. And it is not diminishing.

The approach that I have taken in the preparation of my paper is different from the usual one. Rather than rehash published site management information already available, I have interpreted my assignment as an opportunity to critically assess and to discuss with recreation planners and managers the status and applicability of available knowledge concerned with this important subject. My literature search included published research material from many sources, and recreation site management manuals, handbooks, and supplements of five Federal agencies which receive over 97 percent

of all use which occurs on public lands.

I have not included a discussion of such important values as "esthetics" or "user satisfaction" but they are implicit, nonetheless, in all of my comments and recommendations. Coverage is not limited to the Midwestern situation. I have included material of a world-wide nature, on developed recreation sites and on general forest and wildland areas.

Great amounts of time, effort, and dollars have been spent in the past, are being spent today, and will likely continue to be spent in the future on the management problems of recreation sites. It did not take long after beginning the literature search to realize that one could easily be overwhelmed with published material and by the effort required to obtain it. The literature search yielded over 150 pertinent references and much additional material of only general or limited value. Additional material could have been requested. Several references date back 40 or more years, but most research and administrative studies have occurred since 1960. Several references were obtained from foreign countries. And research continues, as revealed by the large number of studies planned or in progress, especially at universities and at State Agricultural Experiment Stations throughout the Nation. An incomplete listing reveals 40 continuing or planned studies relating to site management.

A thorough study of the substantial pile of reference material received revealed a sizable and important obstacle

relating directly to the question of applicability. This obstacle was the extreme variability of site management problems and the highly specific nature of research studies and findings. Site and area conditions of most study locations have generally been highly variable in relation to soils, climate, topography, vegetation, levels of use, treatments, etc. The first 25 publications I looked at, for example, contained 76 different, major variables and conditions: from high elevation to low elevation, from thin soils to deep soils, from soil series AAA to soil series ZZZ, from wet to dry, from hardwoods to conifers, from high levels of use to low levels of use, from alpha to omega. The unique microconditions and macroconditions which existed from one study area to another seemed to have relegated most completed study efforts to case-history status. Specific cultural and remedial treatments, for site rehabilitation or maintenance, for example, that worked well under one specific stand condition, under one specific set of soil conditions, under one specific level of use, at one specific elevation, will likely not be directly applicable to locations having different conditions and characteristics. And these locations need not be very far apart. In the same watershed, treatments that worked well on east slopes might not work well on south slopes.

It was only after much agonizing and after spending an inordinate amount of time in the process that I realized that the variables and conditions involved in the physical and biological problems of site management were almost unlimited in number and that the pieces of this puzzle already contributed by research and administrative effort seemingly made up only a small part of the total big-picture puzzle and fit together only very loosely indeed. I began to wonder whether available information lends itself to direct and useful application by the majority of recreation planners and managers.

There was only one small, and perhaps inconclusive, check that I could make at this point to help answer my questions about the applicability of research findings. This was to determine, if possible, the use made of research findings by the five public agencies who supply a large share of recreational opportunity in the United States in the preparation of their site management handbooks, standards, and

manuals. I found that the content and scope of recommended practices and procedures varied greatly between agencies, ranging from fairly complete and detailed instructions on certain aspects of site management, to almost complete freedom by field personnel in site management matters. I could not find a single reference in any of the material studied relating to specific research results or research publications. This is not to say, of course, that research results have not been used widely and effectively.

I am in no way faulting any of the excellent studies that have been completed. There have been many of them and they certainly contain a lot of valuable information. For example, in a series of recent studies relating to vegetation management on forested recreation sites: Echelberger (1971) found that well-maintained sites in the Adirondacks deteriorated little during the study period 1964-1969; Beardsley and Wagar in northern Utah (1971) found, among other things, that (1) good site design which includes planned routes for both foot and vehicular traffic and reinforcement of heavy-use areas can substantially reduce or eliminate deterioration of ground cover vegetation on new campgrounds, (2) watering, fertilizing, and seeding to durable species of herbaceous vegetation can effectively increase ground cover vegetation on sites under an aspen overstory, and (3) any site that is artificially watered should also be fertilized and seeded; and Magill (1970) attributed the increase of vegetation on five campgrounds in California to strategically located barriers and to greater precipitation during the 5-year study period.

Research findings such as these have undoubtedly been beneficial to recreation managers on whose sites and areas the research was conducted, and for the specific variables and specific conditions encountered. I am concerned, however, about the untold number of managers who, working perhaps only with very general site management guidelines, are also in urgent need of ready answers and sound guidelines, but on whose sites and areas the results of completed research do not apply directly.

The large number and great complexity of variables involved in site management may well preclude an effective solution by research alone. The piecemeal manner in which we have moved--on a site-by-site and

area-by-area basis--may never get the job done. The job would be staggering when one considers that the USDA Forest Service alone administers approximately 22,000 recreation elements (including water bodies), each of which needs protection and maintenance.

There is a very positive side to past research and administrative efforts, however, despite the fact that many pieces of the site management puzzle are missing and available pieces fit together only very loosely. Many general principles can be drawn from seemingly diverse results and conclusions, and available puzzle pieces can be separated into several piles of related subject matter. One pile consists of soil variables; one of site design and layout features; one of grasses, shrubs, trees, water sprinkler systems, and bags of fertilizer; and one of policy and regulatory and educational matters.

Soil pieces were the most abundant and occupied the center of the puzzle. Soil scientists, landscape architects, engineers, and others are in common agreement that the most essential element in the selection of potential areas for new site development, and in the management of existing sites, is a knowledge of soils and soil characteristics. "The state of knowledge about forest soils has reached the point that we can identify soils that are, or are not, suitable for recreation development, providing that the soil scientist knows for what purpose the soil is to be used" (personal correspondence, NFS, Region 8). Mackie (1965) states that the time is fast arriving when recreation planners will consider a soils map of recreation areas as essential as a topographic map.

The evidence indicates quite conclusively that one of the principal reasons for the widespread site degradation so prevalent today has been the lack of understanding by recreation planners and managers of the vital importance of soil and soil-related factors in the overall site management picture. Many recreational developments which are problem areas today were doomed from the beginning because they were constructed on soils poorly suited to recreational development and use.

The internal and external characteristics of forest and wildland soils are many and are highly variable. Soil interpretations by soil scientists, landscape architects, and engineers can provide in-

formation useful to recreation managers on all phases of site management. A preliminary, low-intensity soil survey made prior to a recreational development can yield such vital information as whether or not a given area is suitable for development; probable susceptibility of the soils to compaction, erosion, flooding, and landslides; and productivity potential and potential use capacities. If the area is deemed suitable for recreational development, or where changes in design are contemplated, a high-intensity soil survey permits interpretations to be made concerning the best locations for family units, buildings, roads and trails, parking areas, pond sites, filter fields, and others. In many cases, such a survey can yield information about fertilization levels and needs, and the vegetation species probably best suited to the site. It identifies fragile areas where recreation use should be restricted or where special reinforcement measures should be used.

The most useful type of soil survey information is the soil series. The soil series is a highly detailed fingerprint of the soil, and represents a large amount of accumulated knowledge which permits maximum interpretation and subsequent use by recreation planners and managers. Similar soil series react alike when used and treated alike, and interpretations made for specific soil series can be used wherever the series is found (Stevens 1966).

The cost of soil surveys is moderate, ranging from \$2-\$3 per acre for low-intensity surveys to \$4-\$8 per acre for high-intensity surveys, depending on soil complexity and the type and amount of information required. Systematic soil survey programs are being made by many Federal, State, and local agencies who will often furnish soils information free of charge. The Soil Conservation Service and cooperating agencies, for example, have been mapping soils and publishing detailed soil maps and reports for almost 30 years. They have recently compiled a classification of Wisconsin soil types and slope gradients according to the degree of limitations and restrictions necessary for successful recreation use without appreciable deterioration (Mackie 1970).

There is still much that must be learned about soils, but a good start

has been made. Major responsibility for the soils phase of recreation site management can likely best be handled by recreation planners and managers, and such agencies as the Soil Conservation Service. Little direct recreation research effort is probably needed. Continuing and careful observation by management of soil behavior under known levels and kinds of recreation uses can be expected to provide continuing improvement in site planning and design.

Site design and layout considerations are the next most prominent features of the picture. Numerous investigators have stressed the essential nature of good site design in site maintenance and management. Orr (1971) states that design is the number 2 variable in site deterioration. Design is one of the critical variables over which management has considerable control and which can be affected most easily. The relative success of the design and ground layout will determine how well a development provides for planned and desired uses within the capacity of the site to withstand them. Design is irrevocably related to maintenance. Poor design, even on good soils, can be expected to result in accelerated site degradation.

Based on the best possible estimate of carrying capacity for each planned site, most often a judgment factor, the development density of planned use must be controlled by the strategic location of facilities, by limiting the number of visitors, by design features which physically limit the number of persons who can occupy the site at any one time, and by site reinforcement measures. Careful placement of facilities, roads, and trails, for example, will direct users away from fragile areas and can significantly reduce deterioration. The fragile portions of sites should be avoided wherever possible or should be reinforced as needed by such materials as asphalt, gravel, sawdust, or soil cement. Barriers, such as fences, rocks, posts, and thorny plant material, should be placed in strategic locations to prevent or discourage unwanted use. Damage to site vegetation can be reduced by placing such things as picnic tables, tent pads, and fireplaces away from the feeding roots of shrubs and trees.

The puzzle becomes alive with grasses and trees and brightly colored shrubs. Be-

sides being an essential element in site esthetics and visitor enjoyment, vegetation plays another major role; it is the best and most permanent method of erosion prevention and control. Of particular importance are grasses and herbaceous vegetation because this understory of vegetation promotes surface aeration and infiltration of precipitation. Vegetation, such as thorny plant material, can be used effectively to control foot traffic.

There is much that management can and must do to protect and promote vegetation on recreation sites and areas. Desirable vegetation of all types should be given maximum protection from physical damage by using sound site design features and reinforcement techniques and materials. Both native and exotic vegetation should be considered and used where appropriate. On many sites and areas it may be necessary to supplement or replace some of the existing vegetation with species better able to withstand impacts of use.

Much research effort has occurred in recent years on testing kinds and species of vegetation for use on recreation sites. There have been many successes and many failures. The failures have been due to several factors, some of which were the use of vegetation poorly adapted to the site, faulty planting techniques, insufficient or poorly timed maintenance, and the lack of protection for new plantings. Perhaps the principal reason for failure, however, has been the use of native and exotic species with little knowledge of the environmental conditions under which a seed parent grew or how a new plant would respond to a new habitat (Magill and Leiser 1972). Tough turf grasses should be encouraged wherever possible because they are generally able to withstand the impact of heavy use.

It is unlikely that utopia will ever be reached, but there are a number of important steps that can be taken. For one thing, recreation planners and managers must make greater use of soil survey information related to selection and use of vegetation better suited to specific site conditions. The site plan and field layout must fully integrate the vegetative component into the total site design so as to provide maximum protection to existing and planned vegetation. Testing of durable vegetative species which can be used over a wide range of environmental conditions should continue. Because of the size, com-

plexity, and cost of the task, however, it is best suited to cooperative attack by several agencies and groups. An excellent example of a cooperative research program in horticultural research is currently underway in California (Magill 1970). The program has drawn together the Department of Environmental Horticulture of the University of California at Davis, the Pacific Southwest Forest and Range Experiment Station, the Environmental Resources Branch of the U.S. Corps of Engineers, the Recreation and Wildlife Branch of the U.S. Bureau of Reclamation, and the Western Service Center of the National Park Service in an effort aimed at testing a wide selection of vegetative species over a wide range of sites and occasions. More such cooperative efforts are needed throughout the United States to supply needed information on a regional basis.

Good husbandry must be provided to the vegetative component of recreation sites. The payoff of sound protective and maintenance practices is amply documented in the large volume of available reference material. Insufficient or poorly timed maintenance are the reasons for much site deterioration which exists today. Recommended cultural and protection measures and practices include: fertilization, irrigation, mulching, shading of planted vegetation, chemical weed control, protection from mechanical injury and theft of small plants, and other treatments. Good site management should also include such silvicultural practices as thinning, improvement and harvest cuttings, removal of overmature and decadent trees, treatment or removal of diseased and insect-infested trees, pruning, brush control, and regeneration measures. Thinning of overstory is an especially important consideration in order to provide conditions favorable to tree reproduction and the development of ground cover species and turf grasses.

Continuing research is needed in cultural and silvicultural aspects of site management. It could be combined most effectively with a cooperative, regional program.

And now we come to the last pile of puzzle pieces. These pieces do not form the picture; rather, they form the border and hold it firmly together. The border represents control, regulation, education, and interpretation. All that planners and managers have accomplished, or will accom-

plish, in good site management will be for naught if sound control and regulatory measures are not formulated and vigorously enforced. In the face of deteriorating conditions we have often permitted overuse and abuse and have provided little or no enforcement of policy. Maintaining recreation use within the physical carrying capacity of a development must always remain a primary objective of management. Our recreation resource must be protected from overuse and abuse. New approaches and new concepts for handling visitors to our recreation sites and areas must be developed.

Educational and interpretive programs also play an important role in recreation site management. Somehow, somewhere, a viable action program must be initiated to develop greater appreciation and perception of the values of nature in our public.

I close with a brief summary and a proposal. Some deterioration of recreation sites is inevitable. Great mountains were reduced to peneplains long before man made his appearance on this good earth. But I think that the evidence is irrefutable that degradation of the Nation's recreation resource has occurred at a faster rate than it should have. There have been many faults and many ills, and numerous indicators that concepts of good recreation site management have not everywhere been applied. We must do better. We must give more than mere lip service to the basic elements of good site management revealed in our picture puzzle.

It does not appear that maximum use has been made of available site management information, possibly because the information was so scattered or was difficult to obtain, or that research findings were not always directly applicable to the situation at hand. Another important reason appears to be the tendency of field managers to disregard research findings. Instead, they seem to apply their own solutions to site management problems as they see them. One large recreation-oriented public agency, for example, does not provide any specific instructions that would tell the field manager how to do the job because they do not want to stifle individual creativity. The danger of this all-too-prevalent situation is clearly seen. Is there not a need to find ways of making research results more easily obtainable and of getting managers to better utilize site management information?

I am convinced that new research is needed and should continue on certain aspects of the site management problem. But I do not believe that this research should continue as it has been done in the past, on a site-by-site and area-by-area basis. This piecemeal attack on the problem cannot provide the greatest good for the greatest number.

I propose that the physical, biological, and social problems of site management be made a research, development, and applications program with many agencies, groups, and individuals participating, and aimed at the solution of regional, rather than local, problems. One of the first steps is to make a much more comprehensive literature search than was possible for me to make within the time constraints under which I worked. A wealth of untapped information exists, in Federal, State, and university research publications; in such Park Practice Program publications as Design, Grist, Guidelines, and Trends; in handbooks, standards, and manuals of public agencies; in circulars and bulletins from State Agricultural Experiment Stations; in administrative studies; in theses and dissertations, and from other sources. A limited amount of field observation and measurement of successful (but unreported) site management installations and practices, and discussions with experienced recreation site managers, would likely pay handsome dividends.

The information obtained as a result of the comprehensive literature search will be voluminous. The next step must be to condense and organize the material into a form that is useful and that lends itself to computer storage and retrieval systems, which will then provide ready access to all interested persons. A system similar to the U.S. Department of Agriculture's Current Research Information System (CRIS) or the INTREDIS Register used for data storage and retrieval in forest pathology (Hepting 1965) could be used. The data base could be updated regularly to include new knowledge as it becomes available. The results of this first effort in the proposed R, D, and A Program would undoubtedly surface many gaps in knowledge which would be expected to have a significant impact on future problem selection and orientation of the research program relating to physical and biological problems of site management.

The importance of good site management information warrants an in-depth effort to find ways to make current and future information readily and easily available to recreation managers and planners wherever they might be located and whatever might be their interest or problem.

## LITERATURE CITED

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- Echelberger, Herbert E. 1971. Vegetative changes at Adirondack campgrounds 1964 to 1969. USDA For. Serv. Res. Pap. NE-142, 8 p. Northeast. For. Exp. Stn., Upper Darby, Pa.
- Hepting, George H. 1965. Codes to the INTREDIS register system for literature retrieval in forest pathology. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, N.C. 61 p.
- Mackie, Donald K. 1966. Site planning to reduce deterioration. *Soc. Am. For. Proc.* 1965: 33-34.
- Magill, Arthur W. 1970. Five California campgrounds...conditions improve after 5 years' recreational use. USDA For. Serv. Res. Pap. PSW-62, 18 p. Pacific Southwest For. & Range Exp. Stn., Berkeley, Calif.
- Magill, Arthur W., and Leiser, Andrew T. 1972. Growing plants on view landscapes and recreation areas. *Guideline* 2(5): 57-61.
- Orr, Howard R. 1971. Design & layout of recreation facilities. p. 23-27. *In* The forest recreation symp., N.Y. Coll. For., Syracuse, Oct. 12-14, 1971, 211 p. Northeast. For. Exp. Stn., Upper Darby, Pa.
- Stevens, Mervin E. 1966. Soil surveys as applied to recreation site planning. *J. For.* 64: 314-316.

## SUGGESTED READING LIST

1. Bates, G. H. 1935. Vegetation of footpaths, side-walks, cart-tracks, and gateways. *J. Ecol.* 23: 470-487.

The effects of grazing, treading, and puddling on the vegetation of footpaths, sidewalks, cart tracks, and gateways in Great Britain are investigated by quantitative and qualita-

tive methods. The effects of these influences on growth and survival of several species of grasses and plantains are discussed.

2. Brame, Robert H.

1962. Maintenance of picnic and camp areas. Seventh Annu. Southeast. Park & Recreation Train. Inst. Proc. 1962: 3-4.

This is a brief report concerning picnic and camp area maintenance and protection measures used on the John H. Kerr Dam and Reservoir in Virginia. Proper fertilization, well-planned and properly developed facilities, and use of native grasses are recommended.

3. Brockman, C. Frank, and Merriam, Lawrence C., Jr.

1973. Recreational use of wild lands. 2nd ed. McGraw-Hill, Inc., 329 p.

This is a generalized introductory text on recreation use of wild lands. Each of the chapters represents a skeletonized treatment of a particular aspect of the recreational use of wild lands. One chapter discusses the tools of the recreation planner and manager relating to physical/biological site management considerations.

4. Burden, R. F., and Randerson, P. F.

1972. Quantitative studies on the effects of human trampling on vegetation as an aid to the management of semi-natural areas. J. Appl. Ecol. 9(2): 439-457.

The authors outline the nature of the changes caused by human trampling in the soils and ground vegetation of semi-natural areas in Great Britain, discuss quantitative methods for relating these changes to the intensity of use, and suggest how these data might be applied in the formulation of management policies for recreation areas.

5. Byrne, T. G., and McNeely, G. H.  
1965. Maintaining your lawns on heavy soils. Univ. Calif., Agric. Ext. Serv. OSA 92, 2 p.

The article discusses such cultural treatments as irrigation, fertilization, mowing, and weed control in maintaining lawns on heavy soils.

6. Carey, John B.

1965. The use of soil survey in making engineering studies in recreation areas. Paper presented to Northeast Conserv. Eng., Northeast Fish & Wildl. Conf., Harrisburg, Pa., Jan. 19, 1965.

A knowledge of soil characteristics is useful in making engineering studies of recreation areas. Soil surveys contain considerable information about soils that can be used by planners in all fields. The key to this information is the soil series names which implies a unique set of soil properties to each soil.

7. Chan, F. J., Harris, R. W., Leiser, A. T., and Paul, J. L.

1969. Factors influencing depth of seeding. Tree Plant. Notes 20(2): 1-5.

The success of direct seeding of woody plants depends, in large measure, on the germinability of seed and environmental conditions in which the seed is planted. This paper discusses the influence of soil temperature, soil texture, and depth of seed placement on the emergence of three woody plant species in California having different-sized seeds.

8. Chan, Franklin J., Harris, Richard W., and Leiser, Andrew T.

1972. Direct seeding woody plants in the landscape. Univ. Calif., Agric. Ext. Serv. AXT n27 (3/72 rerun), 12 p.

Spot seeding of woody plants has been effective, economically feasible, and applicable

in differing terrains. This leaflet discusses the steps for spot seeding woody plants and includes a list of species tested to date that have good potential for success in California.

9. Colman, E. A.  
1948. Soil surveying on wildlands: the problem and one solution. J. For. 46: 755-762.

Soil surveying has developed slowly on wildlands. The importance of such surveys has only recently been appreciated. The author presents suggestions for simplifying field and laboratory work so as to make wildland soil surveying yield the type of information most useful to the wildland manager. The soil survey of a southern California national forest is presented as an example of the application of these suggestions.

10. Countryside Commission.  
1969. Picnic sites. 19 p. London: H. M. Stationery Off.

The report was prepared for those who are or will be concerned with the planning and management of picnic sites. It does not provide a detailed guide to the design of picnic sites, but rather collects together information from a variety of sources and suggests where more technical information can be obtained.

11. Darling, F. Fraser, and Eichhorn, Noel D.  
1967. The ecological implications of tourism in national parks. Proc. 10th Tech. Meet. IUCN (Lucerne, 1966), Part I. IUCN Publ. (n.s.) Number 7, p. 98-103.

This report is a general discussion of the ecological implications of tourism in national parks. Ecological assessment of what is happening within national parks is growing as an art and a science, but is as yet insufficiently employed.

The authors suggest that rather than channelizing visitation towards these areas, recreational areas of various kinds should be established elsewhere than in the national parks.

12. Davis, William B., Paul, J. L., Madison, John H., and George, Leon Y.  
1970. A guide to evaluating sands and amendments used for high trafficked turfgrass. Univ. Calif., Agric. Ext. Serv. AXT-n113, 93 p.

The information in this report is the result of the first part of a continuing laboratory and field study on sands and soil mixes used in high traffic situations in California for the purpose of helping the turfgrass manager to make better informed decisions. The tables and graphs provide practical information that can be most useful.

13. Duncan, D. P.  
1963. How to avoid picnic area deterioration. Park Pract. Guideline, Dev. 11: 67-71.

The author discusses the importance of careful site selection, proper design, and sound management practices in reducing deterioration of picnic grounds. In order to provide high-quality recreational sites and areas, managers and planners must use all available information relating not only to site management and maintenance, but also to original site selection and design.

14. Easterbrook, Arthur L.  
1968. The effects of soil compaction on the occurrence of vegetatively reproducing plants in campsites. Thesis in partial fulfillment of MF, Univ. Mich. Sch. Nat. Resour., 90 p.

Study results revealed that soil compaction within camp-

sites is the major environmental factor which controls the occurrence and distribution of certain clonal plants; i.e., plants that reproduce vegetatively. The sensitivity to compaction of plants that reproduce vegetatively can be generally attributed to their shallow roots. Hence, it appears that vegetative reproduction is not a desirable asset for any herbaceous plant to possess within a campsite. Introduced grasses which reproduce vegetatively, however, are much more resistant and effective in counteracting the effects of trampling and/or compaction. In this study, bluegrass (*Poa interior*) and Fescue-grasses (*Festuca elatior* and *F. occidentalis*) were found to be quite resistant to heavy recreation use.

15. Edwards, R. Yorke

1968. The future of recreation on wild lands. *For. Chron.* 44 (3): 24-29.

The author discusses four measures which can alleviate a decline in the quality of wild rural lands: (1) developed facilities that are designed to limit the volume of use at that maximum level compatible with the preservation of wild values, (2) direct limitation of use at the level beyond which damage would occur, (3) restriction of the kinds of recreational uses most damaging to wilderness, and (4) the use of interpretation programs to influence human behavior so there is an increase in the quality of recreational experience, accompanied by a decrease in the damage done by recreation.

16. Evans, George

1971. Tramp, tramp, tramp...testing turfgrasses. *Now Mag.* 8(1): 8-9.

This paper describes a study initiated during fall 1970 to test 38 different turfgrass

species and varieties for their trampling and drought tolerance. The study will continue for 3 to 5 years and is expected to have significant application in improving turf cover.

17. Frome, Michael

1969. America's campgrounds are turning into slums. *True Mag.*, April 1969, p. 32-36, 109-110.

A journalist's account of growing use pressures and the rapid degradation of campgrounds in the United States. The nature of many of the problems is discussed and several recommendations are presented for solution of the problem.

18. Gibbs, L. C.

1964. Fertilizing ornamental shrubs and small trees. *Park Pract. Guideline, Maint.* 12: 49-50.

The brief article presents a very general guide for fertilizing ornamental shrubs and small trees, including preparation of the soil for planting, time to fertilize, and fertilizer requirements.

19. Harper, John C., II

1964. Turfgrass fertilization of park areas. *Park Pract. Guideline, Maint.* 10: 41-44.

The author discusses fertilization of turfgrasses in recreation areas. Fertilization requirements are discussed for cool season grasses. The importance of liming in obtaining proper soil pH is stressed.

20. Harper, John C., II

[n.d.] Growing turf under shaded conditions. *Pa. State Univ., Coll. Agric. Ext. Serv. Spec. Circ.* 149, 1 p.

The circular recommends 16 maintenance and establishment practices which may improve the survival and growth of turfgrass under trees.

21. Harris, Richard W., and Davis, William B.  
1967. Planting landscape trees. Univ. Calif., Agric. Ext. Serv. OSA 145, 2 p.  
  
This brief report recommends establishment and maintenance practices for planting landscape trees.
22. Harris, Richard W., Hamilton, W. Douglas, Davis, William B., and Leiser, Andrew T.  
1969. Pruning landscape trees. Univ. Calif., Agric. Ext. Serv. AXT-288, 29 p.  
  
Pruning of landscape trees is an important practice for shaping and enhancing plants used in parks, gardens, and wildland recreation areas. This leaflet on pruning is primarily not a product of new research, but is a compendium of existing procedures and practices which can be used as a guide to capitalize on the natural characteristics of each tree species to add interest, beauty, and utility to the landscape.
23. Harris, Richard W., Leiser, Andrew T., and Davis, William B.  
1969. Staking landscape trees. Univ. Calif., Agric. Ext. Serv. AXT-311, 13 p.  
Staking to protect, support, or anchor young trees may be of considerable importance in recreational areas. This bulletin suggests different staking techniques for providing adequate, flexible supports for windy situations and reasonable protection of landscape trees with little or no injury.
24. Harvey, H. T., Hartesveldt, R. J., and Stanley, J. T.  
1972. Wilderness impact study report. An interim report to the Sierra Club Outing Committee on the effects of human recreational activities on wilderness ecosystems. 87 p. San Francisco: Sierra Club Outing Comm.  
This Interim Report primarily outlines the techniques which

are being utilized to study the impact of Sierra Club trips on wilderness and other back-country recreational areas. Research topics include: the effects of trampling on alpine vegetation; the availability, consumption, and production of firewood; the effects of packstock on meadow areas; and the disposal of human wastes and organic garbage. The report contains some preliminary comments based upon the evidence to date, and lists 36 tentative suggestions and considerations for reducing Sierra Club outing impact.

25. Howard, Gene S.  
1972. Plants for problem areas of the western States. Yearb. Agric. 1972, p. 154-167.  
  
The paper discusses factors affecting plant growth in problem areas of the western States and lists over 250 plants suitable for planting, classified by zones according to average annual minimum temperature, annual rainfall, soil pH, and other factors.
26. Hutchison, S. Blair  
1962. Recreation opportunities and problems in the national forests of the northern and intermountain regions. Intermt. For. & Range Exp. Stn., U.S. For. Serv. Res. Pap. 66, 34 p.

This paper describes the recreation situation and opportunity on the national forests within the territory of the Intermountain Forest & Range Experiment Station and identifies the principal problems relative to recreation use. Most of the publication relates to the development of management measures to prevent deterioration of recreation sites and areas. The discussion is relevant not only to national forests of the Northern and Intermountain Regions, but equally as well to all regions of the United States.

27. Jemison, George M.

1967. Impacts of recreation on the ecology of temperate North American forests. Proc. 10th Tech. Meet. IUCN (Lucerne, 1966), Part I. IUCN Publ. (n.s.) Number 7, p. 173-185.

The author discusses the impact of recreation on the ecology of temperate forests in North America. He states that recreation planners and managers are fortunate to have a fund of knowledge to help cope with recreation and its social and biological impacts on the environment, but states that in most cases this fund is only the plateau upon which research must build.

28. Keet, B. J.

1968. Recreation and our soil. Farming in South Afr. 43(12): 75-77.

South Africa only recently joined the field of outdoor recreation. The brief article discusses the importance of protecting the soil of South Africa, not only because of its agricultural and economic potential and value, but also for its recreational potential. The South African Department of Sport and Recreation promises to do everything within its power to promote public consciousness of the theme "Soil is Life."

29. Kraus, O.

1967. Ecological impact of products of tourism and recreation on the countryside adjacent to highways. Proc. 10th Tech. Meet. IUCN (Lucerne, 1966), Part I. IUCN Publ. (n.s.) Number 7, p. 160-169.

The author presents a very general treatment of the ecological impact of tourism and recreation on the countryside adjacent to highways, and recommends regulation and

control to reduce the severity of such impact.

30. Kurmis, Vilis, and Hansen, Henry L.

1969. Occurrence and distribution of pine reproduction in Itasca State Park, Minnesota. Minn. For. Res. Notes 210, 4 p.

This report deals with advance pine reproduction in Itasca State Park in Minnesota. It analyzes the relationships between mother stands and forest types using the synecological coordinate method. The authors conclude that without major disturbance or special silvicultural measures the present area of pine-dominated stands in the park will continue to decline.

31. Lindsay, John L.

1969. Locating potential outdoor recreation areas from aerial photographs. J. For. 67: 33-34.

This study correlated standard photo interpretative techniques with seven criteria for identifying recreation land of high potential. They were population center factors, land use, water value, road systems, vegetation, aesthetic value, and unique features. All but the last two were consistently useful for recreation potential prediction. Seven scales of photography were tested using the criteria named. The 1:12,000 scale proved most effective. The results indicated that aerial photographs can be used effectively to locate potential outdoor recreation sites.

32. Magill, Arthur W., and Leiser, Andrew T.

1972. Growing plants on view landscapes and recreation areas. Guideline 2(5): 57-61.

A substantial cooperative horticultural research program is underway in Cali-

fornia to develop effective solutions to problems of plant establishment and maintenance on difficult recreation sites. The program has drawn together the Department of Environmental Horticulture of the University of California at Davis, the Pacific Southwest Forest and Range Experiment Station, the Environmental Resources Branch of the U.S. Army Corps of Engineers, the Recreation and Wildlife Branch of the U.S. Bureau of Reclamation, and the Western Service Center of the National Park Service. The cooperative research effort is developing a valuable storehouse of information that can be effectively used by resource managers to establish and maintain vegetative cover on a variety of developed site and visually sensitive areas.

33. Magill, Arthur W., and Twiss, R. H.  
1965. A guide for recording esthetic and biological changes with photographs. Pacific Southwest For. & Range Exp. Stn., U.S. For. Serv. Res. Note PSW-77, 8 p.

Photography has long been a useful tool for recording and analyzing environmental conditions. Permanent camera points can be established to help detect and analyze changes in the esthetics and ecology of wildland resources. This note describes the usefulness of permanent camera points and outlines procedures for establishing points and recording data.

34. McCall, Wade W.  
1969. Learn to interpret your soil test results. Univ. Hawaii, Coop. Ext. Serv. Circ. 432, 11 p.

This circular discusses the meaning of such soil tests as pH, available phosphorus, potassium, calcium, and magnesium, salinity, and water, and discusses liming and fertilizer requirements.

35. McCall, Wade W.  
1970. What's in that fertilizer bag. Univ. Hawaii, Coop. Ext. Serv. Circ. 441, 19 p.

The author presents a concise treatment of the fertilizer elements essential for plant growth and lists the average composition of 55 fertilizer materials.

36. McCurdy, Dwight R., and Johnson, Larry K.  
1967. Recommended policies for the development and management of State park systems. South Ill. Univ., Sch. Agric. Publ. 26, 34 p.

This report contains 24 recommended policies for the development and management of State park systems, based on a thorough review and analysis of the existing policies of 39 State park systems in the United States.

37. Meskimen, George  
1970. Combating grass competition for eucalyptus planted in turf. Tree Plant. Notes 21 (4): 3-5.

Using cleared planting spots and fertilizing frequently, 1-year-old quart-potted seedlings of *Eucalyptus camaldulensis* can be converted into an established sapling 15 feet tall with a 3-inch-diameter trunk, and in 2 years the tree can be a major element of the landscape.

38. Meyer, L. D., Johnson, C. B., and Foster, G. R.  
1972. Stone and woodchip mulches for erosion control on construction sites. J. Soil & Water Conserv. 27(6): 264-269.

Mulches of crushed stone, gravel, and wood chips showed great potential for erosion control on construction slopes. Soils covered with 1 inch of stone mulch were much less erodible than those with more than 2 tons per acre of straw. Heavier

rates of stone or 1-1/2 inches of wood chips were even more effective. Good to excellent stands of grass were obtained on many of the stone and wood chip treatments following erosion tests. The study was conducted on a 20-percent borrow-pit side-slope with slope lengths up to 150 feet.

39. Montville, Francis E.

1968. How to plan the recreation enterprise. Univ. Maine, Coop. Ext. Serv. Circ. 396 (revised), 12 p.

This booklet provides a framework for individuals interested in developing a recreational enterprise. A step-by-step approach is given for obtaining pertinent information needed for guidance in the development of a successful income-producing recreation enterprise.

40. National Industrial Pollution Control Council

1971. Land and water pollution from recreational use. NIPCC Sub-Counc. Rep., Dec. 1971, 24 p.

This is a progress report on land and water pollution resulting from recreational use. It contains several major recommendations, and describes related pollution problems and what industry is doing about them.

41. Oliver, Craig S.

[n.d.] Ground cover...nature's garden carpet. Pa. State Univ., Coll. Agric. Ext. Serv. Spec. Circ. 108, 16 p.

Grass is the best and least expensive ground cover, but there are places where it does not grow satisfactorily and is difficult to maintain. There are several typical locations--shady locations, steep banks or slopes, areas where tree roots protrude above the soil surface--where low-growing shrubs, vines, and herbaceous plants are

better suited than grasses for landscape purposes. The circular describes approximately 100 plants that are suitable for specific locations and situations in Pennsylvania and surrounding States.

42. Orr, Howard

1971. Design and layout of recreation facilities. In Recreation symposium proceedings. USDA For. Serv., Northeast. For. Exp. Stn., p. 23-27.

Design of recreation facilities is the number 2 variable in site deterioration. Its relative success will have much effect on how well a development provides for the desired uses within the capability of the site to withstand them. It must be as accurate a solution to the development problem as possible. Design and layout of facilities must be a problem-solving process and one that requires highly analytical and creative capabilities.

43. Partain, L. E.

1966. Use of soils knowledge in recreation area planning. Va. Polytech. Inst. Ext. Bull. 301, p. 180-184.

Research and experience have shown the close relationship between different kinds of soil and their soil and water management problems and production potentials. A soil map properly interpreted can be very useful in selecting and planning sites for camping activities. A useful table is included which shows limitations of sites for camping activities based on drainage characteristics of soils.

44. Rickman, R. W., Letey, John, and Stolzy, L. H.

1966. Compact subsoil can be harmful to plant growth. Parks & Recreation 43 (2): 334-335.

In a large number of naturally occurring soils, claypans and heavy subsoils form a dense layer beneath the soil surface. Most plants grow very poorly in this situation. Drilling 2- to 3-inch diameter holes at close intervals to allow better root development will be beneficial for normally deep-rooted ornamental plants in recreation areas.

45. Rudolf, Paul O.  
1967. Silviculture for recreation area management. J. For. 65: 385-390.

The importance of the forest in providing outdoor recreation has been recognized for a long time, but management of the forest for that purpose often has had to take a back seat. Cultural practices for producing and tending forests usually can be so applied and so modified as to provide, maintain, or improve recreational values. The author describes some ideas on how silvicultural practices can be used for developing recreational areas.

46. Saito, K., and Tachibana, H.  
1969. Influences on human impact of forest vegetation in Japan. I. Changes in forest vegetation and soil due to impact in Sendai Area, Miyagi Prefecture, northeast Japan. Ecol. Rev. 17(3): 131-152.

Few intensive researches have been made on the dynamics of the forest ecosystem caused by human impact. The writers' aim was to reveal the causal relation between the vegetational and environmental changes of the forest induced by the increasing impact of man. The first attention is focused on the changes of the vegetation and the soil in the course of retrogressive succession from the climax forest to the secondary one.

47. Stankey, G. H., and Lime, David W.  
1973. Recreational carrying capacity: an annotated bibliography. Intermt. For. & Range Exp. Stn., Tech. Pap. (In press).

This publication contains almost 200 annotated references pertinent to carrying capacity decisionmaking. The contents of the bibliography are arranged into four parts: (1) the concept of carrying capacity, (2) biological investigations of recreational carrying capacity, (3) investigations of aesthetic carrying capacity, and (4) managing for recreation carrying capacity.

48. Steiner, Wilmer W.  
1972. Gardening to help solve your erosion problems. Yearb. Agric., 1972, p. 9-16.

Selecting proper plants, choosing the best ways to get them established, and then deciding on treatment measures for long-term management of the protective vegetation are all-important steps in developing and maintaining erosion-resistant vegetative cover. The article includes a brief discussion of techniques for vegetative management, and advises that persons and agencies having conservation problems should seek local help from soil conservation districts or from Soil Conservation Service and Extension Service offices.

49. Stone, Oscar P.  
1967. Tree care with liquid feeding needles. Trees Mag. 22(6): 14-15.

The author discusses the use of liquid feeding needles in conjunction with hydraulic sprayers in feeding trees. With modern developments in water-soluble fertilizers, the use of this method of plant invigoration and nourishment has become a great

help in keeping trees, shrubs, and flowers in more active growth. The addition of systemic insecticides to the fertilizer mixtures will more easily control scales, aphids, leaf miners, and other hard to control insects.

50. University of California, Department of Environmental Horticulture

1971. Establishment of woody plants by direct seeding in California. Coop. Publ. U.S. Dep. Transp. Fed. Highw. Adm., Bur. Public Roads & Calif. Dep. Transp., Div. Highw., Highw. Res. Rep. July 1971, 81 p.

This bulletin characterizes some of the site problems associated with landscape planting of woody plants in areas of low rainfall in the Southeastern United States. The main findings of 3 years' laboratory and field studies was that direct seeding of perennial plants offers the possibility of low initial investment and minimum maintenance. The report describes seed handling and planting procedures, presents results of representative planting trials, and lists species that have been found satisfactory for specific situations.

51. USDA Agricultural Research Service

1962. Understanding soil compaction. Agric. Res. 11(2): 7.

Results of USDA experiments by ARS soil scientists to determine why plant root growth is restricted or halted by layers of compacted soil revealed that root growth slowed or stopped only when the soil had so much resistance to penetration (strength) that roots could not force a passage. The information will be useful in designing tillage systems for soils where compacted layers are a problem.

52. USDA Forest Service

1962. Working drawings of basic facilities for campground development. Agric. Inf. Bull. 264, 23 p.

This bulletin contains self-help suggestions and a set of working drawings of basic facilities for campground development intended to aid the landowner in planning, building, and maintaining the basic facilities for a family forest campground or picnic area as a private business venture.

53. USDA Forest Service

1965. The American outdoors--management for beauty and use. Misc. Publ. 1000, 76 p.

The U.S. Department of Agriculture has been steadily developing useful ways and means for maintaining and restoring the natural beauty of outdoor America. This booklet outlines some of the approaches to beautification along with use of the land. It also lists sources of further information and technical assistance.

54. USDA Forest Service

1970. Soil survey procedures handbook - 2509.14, p. 55.24--1(2) - 55.24--17. In For. Serv. Handb. R-8 Suppl. 1.

This Region 8 Supplement to USDA Forest Service Soil Survey Procedures Handbook (FSH 2509.14) describes procedures for the application of soils data in recreation resource programs. Detailed procedures are outlined for preparing a Stage 1 Soils Report prior to land acquisition when primary justification is for recreational development, and a Stage 2 Soils Report in recreation design for all existing sites as changes in design are contemplated and on all proposed recreation development sites.

55. USDA Forest Service

1973. Recreation management - 2300, p. 2331.1--1 - 2331.1--9. In For. Serv. Man. R-2 Suppl. 62.

This Region 2 Supplement to USDA Forest Service Manual 2300 describes the procedures to be used when preparing recreation site plans. A detailed description is given of the content requirements of each site plan, and includes: (1) narrative design report, (2) detailed site map, (3) preliminary design concept, (4) general plans, and (5) final construction plan.

56. USDA Soil Conservation Service  
1966. Guide to making appraisals of potentials for outdoor recreation developments. 72 p.

The purpose of this guide is to provide a systematic approach to appraising the potentials for future outdoor recreation development in an area the size of a county or small group of counties. It can be adapted to areas such as watersheds or trading areas of similar size. The information provided and the conclusions reached are useful in recreation programing and planning by soil and water conservation districts, counties, and by agencies working in such areas.

57. Van Dersal, William R.  
1972. Adventures with native plants that passed their 'tests.' Yearb. Agric., 1972, p. 176-184.

The author discusses several important management practices for growing native plants in gardens. Also included is a partial listing

of trees and shrubs considered by gardeners and horticulturists to be the very best for various parts of the United States.

58. Volk, Gaylord M.  
1964. Know your fertilizers. Univ. Fla., Agric. Ext. Serv. Bull. 177A, 25 p.

This bulletin presents a discussion of the information found on the tag attached to containers of fertilizer. The author stresses the fact that an understanding of the information found on fertilizer tags can often prevent needless expenditures for materials containing unnecessary elements, or crop losses resulting from the use of materials lacking in some essential plant food.

59. Walker, Laurence C.  
1964. Fertilizing shade and forest trees in parks. Park Pract. Guideline, Maint. 11: 45-47.

This article describes procedures for applying dry and liquid fertilizers to established shade and forest seedlings, sapling and larger trees, and recommends practices for fertilizing trees at the time of transplanting.

60. Youngner, Victor B., Madison, John H., and Davis, William B.  
1966. Which is the best turfgrass? Univ. Calif., Agric. Ext. Serv. AXT-227, 2 p.

The circular evaluates 12 popular varieties of common turfgrasses for 14 important characteristics and requirements.

# RECENT DEVELOPMENTS IN LANDSCAPE ASSESSMENT RESEARCH WITH IMPLICATIONS FOR MANAGING FOREST LAND FOR RECREATION

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**ABSTRACT.**--Several recent studies in psychophysics, forest aesthetics, and landscape assessment are reviewed which suggest that forest vegetation can be managed as a visual resource. On flat and undulating land, as found along the Great Lakes and Atlantic seaboard, the visual interest in the landscape depends largely upon the distribution of open and forested land. Patterns of open and forest land are considered that would enhance the visual interest and spatial variety on flat, forested land for those recreational activities involving movement through the landscape.

## INTRODUCTION

The importance of managing forest vegetation for its visual amenities has been recognized by the Forest Service, and has received particular attention over the past several years (USDA Forest Service 1973). An appreciation for the visual composition of wooded environments is deeply rooted in western civilization, and the tradition of managing vegetation as an object of enjoyment is well established (Zube *et al.* 1971).

The visual qualities of forest landscapes are sources of stimulation and enjoyment in a recreational environment. The visual content and composition of the physical environment influence the recreation experience, and where recreation is the predominant use of forested land, the visual qualities of the land and the vegetation can become an important recreation resource. However, the particular aesthetic attributes of forest vegetation are complex and elusive, and difficult to describe and evaluate in terms that persons of diverse backgrounds and sensitivities can agree upon.

This paper will review several recent research efforts which seem to have implications for managing forests as visual recreational resources. Several research efforts in the areas of perceptual psychology and psychophysics have been directed at understanding the mechanism by which the visual environment is perceived. Also, several models have been recently developed by landscape planners to inventory and evaluate visual quality over broad regions for the purpose of reserving recreational resources and predicting change resulting from future development. The recreational activities most affected by the visual qualities discussed here are those activ-

ities in which people are moving through the landscape and experiencing sequences of spaces and views as they do while riding, walking, or boating.

## RELEVANT STUDIES IN PSYCHOLOGY

Several investigations in visual perception and behavioral psychology point to certain abstract elements in preferred scenes which can be measured and quantified. Such measurable abstract elements could be used as a basis for inventorying and evaluating visual resources.

One psychological study (Mackworth and Morandi 1967) sets out to determine whether adults looking at a pictorial display sought out certain dominant details, and whether it mattered at all where they focused their eyes when viewing a picture. The study concluded that the highly repetitious, smooth-textured elements were overlooked in favor of the less frequent and unusual details in the pictorial display. In other words, adults are very specific in what they focus upon and, furthermore, they are consistent in the particular elements which they focus upon. Attention tends to be directed to the edges between contrasting even-textured surface areas in photographs. The eye movement recorder used in this study measured the rapid shifts in eye fixations and accurately described the points in the pictorial display that the eyes fixed upon momentarily.

The eye-movement phenomenon reported by Mackworth and Morandi was explored further by Gratzer and McDowell (1971) who used black-and-white photographs of forest scenes, five of them taken of National Forests, and five taken of scenes in the rural Connecticut countryside. Gratzer and McDowell's study showed, as expected, that the eye fixated most often along

edges--along shoreline, skyline and ridgelines, along lines separating distinctive vegetative types (as between pasture and woodlot) and along the edges of strong shadows. In certain photographs a few fixations occurred on small objects that stood out from the background--a snag amidst even-textured foliage, or a bright patch of grass amidst dark foliage.

This study suggests that in forested settings attention is focused on the edges between large, contrasting, even-textured masses, or on small, outstanding objects. The eye does not wander within large, even-textured masses but rather the eye concentrates upon the edges between contrasting masses of even texture and on a very few small but outstanding visual elements.

Eye movement studies do not appear to give any indication as to the observer's preference, nor do they suggest how the observer evaluates the content of the scene. Eye movement studies do show that attention is attracted to abstract features, such as edges, and particularly those edges between a few, contrasting masses and forms. The eye skips over the commonplace, the redundant elements to single out a few singular, distinctive elements.

Another germane avenue of psychological research is that of stimulus complexity and exploratory behavior pioneered by Berlyne (1960). Berlyne maintains that complexity increases with the number of distinguishable elements, that complexity increases with dissimilarity between elements, and that complexity varies inversely to the extent that several elements are perceived as a unit. Berlyne, investigating the relation between complexity level and human preference, has found that with increasing levels of complexity preference increases also, but beyond a critical level of complexity, preference decreases.

Wohlwill (1968), investigating some of Berlyne's concepts, related complexity in the visual environment with the preferences of individuals. The results seem to substantiate Berlyne's theories. Two sets of photographic slides, one set of landscape scenes, another of abstract paintings, were scaled according to their complexity. Complexity was rated as to color, directions of dominant lines, texture, shape, and artificiality. As expected, preference increased with increasing levels of complexity up to a point beyond which preference decreased. The particular critical point in complexity appears to vary among individuals depending upon their famil-

ilarity with the visual environment and other factors. However, the concept is intriguing when considering the evaluation of forest landscapes for their visual interest.

These three studies indicate that certain abstracted, visual elements in forest settings might serve as a basis for estimating the visual interest of forested settings.

## A MODEL OF SCENIC PREFERENCE

Several studies by Shafer of the Northeastern Forest Experiment Station have identified a few quantitative variables in wildland scenes of high scenic quality which substantially account for the scenic preferences of wildland recreationists in New York State and Utah (Shafer *et al.* 1969, Shafer and Mietz 1970). The relevance of Shafer's model to landscape management lies in the importance it attaches to the edges and the area of water, massed vegetation, and exposed ground as a measure of visual appeal and interest.

A photograph was divided into three distance zones (immediate, intermediate, and distant). Then measurements were taken in each distance zone of the perimeter and area of such elements as vegetation (trees and shrubs), nonvegetation (grass, bare soil, and rock), and water. A mathematical model containing certain combinations of the perimeter and area measurements provided an estimate of the preferred visual quality of the photographed scene. Through factor analyses, the following measurements were found to contribute to a high preference rating: (1) perimeter of immediate vegetation, (2) perimeter of intermediate nonvegetation, (3) perimeter of distant vegetation multiplied by area of water, (4) area of intermediate vegetation multiplied by area of distant nonvegetation, and (5) area of intermediate vegetation multiplied by area of water. The predicted preference score obtained from measurements on the photographs was compared to the actual preferences expressed by campers in the Adirondacks for the same photographs. The predictive model explained 66 percent of the variance in camper preference. Similar results were obtained when the preferences of hikers in the Wasatch Mountains of Utah were compared with the model's predictive score; again 66 percent of the variance in preference was explained.

Shafer's model, based upon measurement of edges and areas of visual forms on photo-

graphs, provides a convenient estimate of scenery preferred by wildland recreationists. It can be used in planning new facilities to predict preferences at given locations. It can also be used to study the visual elements in a given scene which contribute to its preference rating.

#### A LANDSCAPE CLASSIFICATION MODEL

There is one other thread to be woven into this discussion before we consider the visual aspects of forest management practices. That is the relative importance of landforms and forest vegetation. One basis for estimating the relative importance of forest vegetation as a visual resource is provided by Zube's model for classifying and evaluating landscapes on a regional basis (Reg. Plann. and Design Assoc. 1970). This model recognizes landform as the most fundamental visual criterion for classifying areas within a broad region.

Zube classified the landforms of the North Atlantic region as mountains, steep hills, rolling hills, undulating land and flat land, depending upon the relative relief between valley floor and ridgelines over large areas of 100 square miles or more. Landforms are an appropriate basis for classification because they are the most permanent and enduring visual elements in the landscape. Landforms determine the course of streams, and the contours of natural and artificial bodies of water. Dominant landforms--mountainous and hilly terrain--define major spaces and provide elevated vantage points from which to view broad expanses of landscape. Areas of less dominant landforms--undulating and flat lands--are less visually interesting as they do not have broad vertical elements to define major spaces, or elevated vantage points to provide wide and distant views.

The landscape classification model further subdivides the land within each landform class according to the pattern of surface elements on the land. The three elements which are considered to be visually significant are:

- (1) open land - fields, pasture, marsh,
- (2) forested land - forest, woodlots, and
- (3) urbanized land - containing clusters of buildings and other man-made structures.

The landscape classification model provides a basis for rating the relative importance of forest vegetation as a

determinant of scenic quality in areas where landforms are less dominant, such as the land Zube classifies as flat and undulating. Flat and undulating landforms are characteristic of the heavily urbanized North Atlantic seaboard, and also much of the land surrounding the Great Lakes.

#### IMPLICATIONS AND APPLICATIONS

Let us consider, for a moment, forest vegetation strictly as an object to be managed for its visual interest in recreational settings. The eye-movement studies suggest that some monotonous landscapes might be made more visually interesting by creating more edges and providing masses of contrasting tone and texture. Since vegetative patterns are most easily manipulated, an increase in the number of exposed edges between forest land and open fields or water should enhance scenic quality. Yet Berlyne's research suggests that there may be a limit to the extent by which edges can be increased without impairing scenic interest.

Assuming that on flat and undulating land the visual interest in the landscape largely depends upon the variation in vegetative cover, the following examples illustrate how forestation and clearing of forest land might affect the scenic interest of the landscape.

The findings of the studies discussed so far would suggest that in rural land with relatively flat terrain, the distribution of forested land and open land would largely account for whatever visual interest there was in that landscape. Open land is here defined as land devoid of tall trees, and would include fields, pastures, clearings, marshes, and water surfaces. Forested land is defined as continuous tree cover.

Consider a situation where terrain is covered with low vegetation, grasses, or other herbaceous cover. The view of a person standing in such a landscape is unobstructed in all directions and most of the visual interest lies in whatever pattern may occur on the ground below him and extending up to the horizon.

Suppose blocks of forest vegetation were added to this open landscape. Edges between wooded tracts and open land provide strong visual contrasts that attract attention. Spaces are defined by the vertical masses of trees. The view to the horizon is partially obstructed, and the visually constraining blocks of forest

vegetation define major spaces in much the same way that mountain and hill landforms shape spaces and vary the distance one can see in certain directions. Even recognizing that blocks of trees are not substitutes for hills and ridges, it would be reasonable to expect that by introducing distant blocks of trees onto otherwise open, flat land, the scenic quality would be enhanced.

Now take a situation on the other extreme, where flat terrain is under continuous forest cover. A person standing within the forest can see only a short distance in any direction. The space is extremely confined by tree trunks and the overhead canopy. There is little contrast in visual forms to create edges. However, where clearings occur as breaks in forest cover, edges are created. Strongly defined major spaces will result. They are similar in their visual effect to the spaces shaped by mountains and hills. Masses of trees provide the steep vertical walls that confine the view. The swath cut through the forest for a road resembles a canyon carved into bedrock. The sloping profile at the edge of a clearing where tall trees blend into tall shrubs, low shrubs, and herbaceous growth, appears much the same as the profile of a steeply sloping hill.

On flat and undulating terrain, steeper landforms can be simulated by structuring vegetation of varying height and growth forms. Likewise the relief of flat and undulating landforms can be exaggerated by maintaining a high profile of forest vegetation on the rises and ridgelines and by keeping most of the flood plains and valley bottoms relatively open. The natural drainage pattern might well serve as a basis for organizing spaces of open land bounded by forest. Sequences of spaces of varying dimensions could provide a more stimulating visual recreational environment, particularly for persons moving through the forest-defined spaces.

The distribution of forest vegetation and open land can also be considered in terms of visual complexity. Level terrain with a highly diverse spatial organization of blocks of trees and open land of varied sizes and dimensions can be extremely complex and disorienting to some people; or conversely level land that is entirely forested or entirely open can be simple, predictable, and perhaps boring to others. Although further studies of recreationists' responses to complexity of spatial organi-

zation on forested sites are needed, some intuitive consideration for spatial complexity can be given when planning and designing sites for forest recreation.

There is justification for managers of forested recreation sites to consider forest vegetation as a visual resource, and as an object to be manipulated for its visual stimulation. Native trees, shrubs, and herbaceous vegetation might well be manipulated to vary the visual interest and stimulation they might afford to recreationists as they pass through rural forested environments.

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# VISUAL VULNERABILITY OF FOREST LANDSCAPES

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**ABSTRACT.**--Broad land-use planning, preparation of environmental impact statement, and detailed multiple-use planning all need to recognize that the visual landscape will be altered by physical results of management decisions. Certain landscape characteristics can be used to predict vulnerability or resistance to visual impacts of man-made changes, such as roads or timber harvest. For planning and design purposes, impact prediction needs to precede detailed knowledge of what the impacts themselves may be. Sources of visual landscape vulnerability or resistance are related to (1) landscape compositional types, (2) sensitive parts and locations found in landscape, and (3) outside influences and inherent effects, such as orientation, climate, seasons, slope and soil and vegetation surfaces. Some rankings on levels of visual vulnerability are posed.

This paper suggests a way to predict, or at least to anticipate, where a landscape will be visually vulnerable or resistant to change, identifies some sources of visual vulnerability, and ranks the levels of vulnerability for some of the more sensitive parts of the landscape.

## SOURCES OF VISUAL VULNERABILITY

Landscapes include a vast array of variable components and characteristics. Therefore, it is not easy to say with finality why some landscapes are more sensitive to visual impacts than others. However, three sources of visual vulnerability can be identified in the landscape itself: (1) the presence of distinctive landscape compositions (types), (2) sensitive parts and locations, and (3) outside influences and inherent effects. Within these sources a range of sensitivities will be encountered.

Considering what in a landscape makes it more vulnerable or less to visual impacts involves the same factors that I have used in making scenic analyses and landscape inventories (Litton 1968, 1972; Craik 1972). Developing an inventory of the landscape is necessarily the beginning of a selective and evaluative procedure. And the concern for visual vulnerability may be considered a special category of landscape analysis and inventories.

## LANDSCAPE COMPOSITIONAL TYPES

Landscape types are conspicuous visual compositions which display high (or distinguishable) levels of esthetic qual-

ity. As these occur, greatest visual vulnerability should be expected. Such types are composed arrangements which have, in esthetic terms, unity, vividness, and variety (Beardsley 1958). In the landscape, one kind of unity is that of a dominant landform with coordinated, subordinated, surrounding parts. Vividness can be expressed by contrasts of elements such as color, line and shape. Variety (or richness) is usually that of numerous and different parts seen together. All of these conditions found joined to form specific landscape types will be in nodes (Appleyard *et al.* 1964) rather than being the continuum of more usual open space surroundings which I call the "ordinary" landscape.

Ordinary landscapes lack the distinction of landscape compositional types, and we tend to take them for granted. Normally extensive, their major value is in a regional integrity or unity. Yet they are apt to lack the significant variety and vividness expected in the landscape types. In Beardsley's words (1958), they are characterized by "indifferent differences." Ordinary and distinctive landscapes complement one another and together make the whole landscape.

Visual vulnerability is less obvious in ordinary landscapes than in distinguished landscapes. But impacts of degradation, after slowly accumulating, can be just as devastating. This impact suggests that visual vulnerability is of two kinds--that which is immediately obvious and that which occurs slowly, developing over time.

Several selected landscape types such as feature, enclosed, and focal landscapes, will illustrate more specific sources of visual vulnerability (Litton 1968).

Feature landscapes are built upon such readily identified elements as a dominant landform; for example, an obvious water display, such as falls, or a specific part of vegetative cover, such as a significant grove or cove of trees. Or these conspicuous expressions of terrain, water, and plants may be found together. Visual contrasts giving particular definition to features--but to other landscapes as well--can include dissimilarity from surroundings (apparent isolation), significant scale differentiation, contour distinction of earth-sky silhouette, water surfaces, and edges against terrain or vegetation. These kinds of contrasts or sources of vividness which demand our visual attention also explain why the potential for visual vulnerability is high. Additionally, a landform feature (and other terrain faces) may be given distinction by such surface variations as a mosaic pattern of vegetative cover. However, a complex surface pattern can also hide and obscure alterations so as to reduce visual vulnerability.

An enclosed landscape, another positive compositional type, is an expression of limited, three-dimensional space. It can typically be represented by a named valley, with well defined encircling walls and clean cut bottom. Distinction lies in the simple unity of the composition and particularly in the nature and proportions of walls and bottom. Visual vulnerability will be highest in relation to the walls and their surfaces, and also to the junction between the floor and walls. The threat is to break or detract from the ring-like compositional structure.

A focal landscape, one kind being a straight segment of a riverscape, draws and focalizes attention. A series of essentially parallel lines appear to converge toward a point or terminal area in the distance. The area of focalization is the most vulnerable part of the composition since attention is directed there. The parallel lines are those of water-land edges, riparian borders meeting upland vegetation, and perhaps banks or cliffs carved by stream erosion. Breaking and disrupting these lines is a secondary source of visual vulnerability.

Because the landscape types are readily identified compositions and they tend to contain esthetic quality in good measure (Cralk 1972), they are especially vulnerable to vis-

ual impacts. The threat is to their special lines, surfaces, and proportions and eventually to the completeness and stability of their composition.

### Sensitive Parts and Locations

Some parts of the landscape or locations upon it will be recognized as more sensitive to impacts than others. Edges--visual junctions of parts--are especially vulnerable to disruptions. Different locations--identified as places higher or lower in the landscape--will show different levels of sensitivity to impact. Rankings of vulnerability are suggested for some selected edges and locations.

#### Edges--Ranked for Vulnerability

- (3) Ridgelines separated in space and viewed against the background foil of more distant land surfaces (Gibson 1950). This third ranking is a

Where edges of dissimilar composition come together are lines and areas highly vulnerable to the impact of change in a landscape. Sky, water, land, and vegetation are the ingredients in the mosaic. Examples of meeting of diverse ingredients would be sky with land or forest, water with beach or riparian strip, ridgeline with distant surface, mineral face with brushland, and conifers with hardwoods. The visual relationship of one to the other runs the gamut in contrast--from high to low. The more conspicuous a meeting of ingredients, the more vulnerable it is to the impact of change. For edges I suggest the following ranking, from highest to lowest, of vulnerability:

- (1) Skylines in any landscape, whether ordinary or special. They are the most sensitive because of the way they display changes. Two completely contrasting elements offer the strongest visual junction. The darker terrain solidity is in sharp contrast to the lighter film color of sky or the brightness of clouds.
- (2) Edge and edge zone where land and water meet. Water has certain of the characteristics of sky--fluidity, life, and reflective brilliance. Normally, it is significantly lighter or darker than the adjacent vegetation or land surfaces (Litton *et al.* 1971).

"sometimes thing" because ridgelines may occasionally be skylines. Or they may be seen but poorly; the color-texture characteristics of the background foil can be close approximations of the ridge itself.

- (4) Edges and mosaic areas which occur on the face of land. These kinds of faces consist of a variety of mineral or soil surfaces and vegetation types seen together. Their relationships suggest a broad range of contrast differences. An example would be the difference in visibility between light gray granite and dark green scrub oak; another would be sere grassland meeting a Douglas-fir forest.
- (5) Junctions between dissimilar woody plants. An example would be an aspen grove surrounded by lodgepole pine. Other vegetation types compared can be visualized as having even more subtle relationships. And so this rank list could be carried down to levels approaching imperceptibility.

The edges and areas of plants and mineral which create a surface pattern have generally a much lower vulnerability than do these junctions which include sky or water. This effect is based on the potential for camouflage or absorption into the pattern if man-made alterations are designed with conformity to that pattern. Without conformity or other compatible relationships established in alterations, vulnerability becomes an open question. It must be recognized that the rankings I have proposed only represent tendencies of what to expect. Other factors may become dominant and exceptions must be expected.

#### Locations

There are several locations upon the face of the landscape where vulnerability varies. I refer particularly to elevational positions, some of which have also been suggested in the discussion of edges. Another hierarchy or ranking can be indicated to predict how obvious impacts can be (U.S. Forest Service Wyoming Study Team 1971). Higher locations are in general apt to be more apparent than lower ones.

A timber harvest is a well known kind of impact. And it is one of the most con-

spicuous as it involves skyline silhouettes and upper parts of ridges. Visual attention is directed to the maximum contrasts where sky and solids meet. Furthermore, the higher the location the greater its visibility from greater distances and from a more extensive area. And there is very little chance for effective screening.

A less conspicuous visual location will be that at the center of forested faces. In clearcutting as an example, contrasts between disturbed soil or grass and forbs against dark surrounding forest are the source of the display. And they can be strong indeed. Yet impacts of change in this mid-level location will not be seen from the full range of distances and broader areas that are true for higher positions.

The least conspicuous location--the area of least vulnerability--is low in the landscape, as for example, the bottom edge of forest land where it may often meet a dissimilar vegetation type. Changes in edge and perimeter enlargement are impacts not readily apparent as seen from low eye level or as viewed on a flat plane. It is here that details of impact can stand out as viewing distances tend to be short. But there is a high potential for screening by vegetation and terrain. It can also be expected that visibility is restricted to the smallest number of viewing points as a comparison is made with impacts in higher locations.

Again, while a hierarchy for vulnerability can be suggested for higher to lower locations of impacts, it must be recognized that exceptions will be found. Prediction of impact intensity will improve as we know better what the nature of the impact may be.

#### Outside Influences and Inherent Effects

Such ecosystem components as climate, microclimates, topography, and soils (Daubenmire 1968) can also be examined for ways they modify appearance of the landscape. They can also affect sensitivity or resistance to visual impacts. Generally, they are either regional in scope or applicable to any landscape. By "outside influences" I am referring to certain aspects of orientation, climate, and seasonal effects. And by "inherent effects," I mean differences of topographic slope, certain soil characteristics, and some kinds of vegetative covers. I recognize that it is not altogether possible to isolate the different components which come together to make the landscape. Yet it seems essential to try to separate them for the

sake of weighing factors and of establishing better understanding as to vulnerability sources.

#### Outside Influences

Controlling sunlight, insofar as it affects the broader landscape, is not within the manager's capability. But we can observe that different exposures influence contrasts in vegetative types. On the Pacific Coast, for example, a commercially important tree species may occur on a northerly face while the opposing southerly face can well be grassland. As a consequence, we could expect the impact of logging on one side but not the other--a difference in visual vulnerability. In an opposite vein, grassland would reveal road construction while timber could screen it.

Beyond differences of cover and surface with their contrasts in reflection or absorption of light, there are other differences in visibility related to orientation. For the northern hemisphere, surfaces exposed to the south will tend to be fully lit by the sun during most of the day. What happens there will be more conspicuous than in north side exposures, where back-lighting and shadows will tend to shield and obscure. East and west orientations have a certain equality of visibility but at opposite times of the day. As morning light illuminates an east face, the west side will be in shadow--and the reverse for the afternoon. But a western exposure compared to eastern, suggests a more critical microclimate from afternoon heat intensity. For regeneration or replantation this could be interpreted as greater visual vulnerability than expected on an east side face or even the south. Thus light and shadow involved with orientation suggests a vulnerability ranking which is greatest for the south, followed in order by the west, east and the north. Climatic influences can, however, be expected to modify this ranking.

Different regional climates can, in oblique fashion, provide differences in visual sensitivity. Climates are directly linked to the nature of native cover and to vegetative recovery or regeneration after disturbance. The influence of New Mexico's aridity, California's Mediterranean climate, or Tennessee's humid climate suggests a scope of effects which can be expressed as vulnerabilities. After 30 years, the U.S. Army's tank tracks remain apparent on the military reservations in the California

desert. Had Tennessee provided such a site, signs would have long since disappeared. Also related will be the ways in which storm patterns or intensities can be revealed in either erosional tendencies or deeper instabilities of certain soils.

Seasonal effects indicating changeable vulnerability can be as obvious as the wintertime openness of deciduous hardwood forests. Abandoned coal stripping banks in Appalachian hardwoods are never more apparent than in winter. By comparison, the evergreen forest is inherently stable, and screening is not a seasonal matter. In another effect, autumn foliage coloration may be especially significant in localized situations--temporarily producing feature landscapes. These will have their sphere of visual influence within which vulnerability to impact will be high. Similar observations may be made for areas where significant spring bloom occurs. Yet in the off-seasons, will these vulnerabilities be remembered?

#### Inherent Effects

Landforms and their particular range of topographic slopes are a primary means of defining different kinds of regional landscapes (Res. Plann. and Design Assoc. 1970). Within whatever landscape we care to consider, a crude axiom may be suggested: "The steeper the slope, the greater the potential for visual vulnerability." Several reasons support this--one is perceptual, another is impact scale and repair.

On flat and gentle sites, we observe with a nearly level line of sight. As a result, much is hidden by overlapping objects and perspective foreshortening. Screening is almost automatic. As we observe steeper and steeper slopes rising up in front of us, we see increasingly more of the slope surface and whatever it supports. Screening is not apt to be effective. Also, an activity such as road construction will occupy increasingly larger amounts of transverse area as slopes steepen. Thus, the scale of impact tends to grow and the scope and difficulty in re-establishing vegetation and soil stability also expand. Through suitable studies, critical ranges of slope and attendant levels of impact should be identifiable.

Soil color, particularly that of disturbed soil, is significant in the strength of visual landscape images. If exposed soils are dark, they are apt to be less apparent because they tend to match the usual

dark values of vegetation. The difficulty is that disturbed soils are usually lighter than undisturbed ones--a source of visual contrasts. The other complication is that wildlands soils, especially on steeper slopes, tend to be in the lighter color ranges of gray, yellow, or red. If it were possible to have the black loams of Illinois wherever an impact occurred, we could be less concerned with how soil disturbance relates to visual sensitivity. Beyond the simple fact of soil color is the matter of its inherent capacity to sustain plants. The light-colored soil which is hostile to plant growth carries vulnerability one step further.

Distinct patterns of vegetation and perhaps mineral exposures can absorb visual impacts if that existent mosaic is used as a guide to the design of alterations. But there is another aspect to this--what if the vegetative surface is essentially of uniform texture? Examples of this simplicity include the Douglas-fir forests of Oregon or those of lodgepole pine in Wyoming. They show but minor variations. Except for the minute visual (and physical) contrasts that result from stand variations, little guidance is offered that we may follow. Such simple textures explain in part--why the impact of clearcutting in these forests is so conspicuous, why visual vulnerability is high. To reduce such impacts, we need a more sophisticated design process, one based heavily upon the scale, the landform variations, and characteristics of the particular landscape involved.

### Conclusions

The sources of visual vulnerability which I have identified are probably not new to you. What landscapes you have within your own purview can suggest more specific kinds and ranges of vulnerability. My thesis is this: before you consider the impact of any alterations, first look at the landscape as a resource in its own right and analyze its visual vulnerabilities. With this background of understanding, it should be much easier to arrange for designing alterations for proper fit to the landscape.

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## DISPERSAL OF RECREATIONISTS ON WILDLANDS

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**ABSTRACT.**--A variety of automated reservation systems are now in use at or proposed for State and Federal campgrounds and parks. A research program to study problems associated with the dispersal of recreationists on wildlands is underway. It will evaluate and compare reservation and referral systems, evaluate operational systems, attempt to design a visitor dispersal system, and determine the applicability of dispersal systems to recreational uses other than camping.

### INTRODUCTION

In all parts of the United States, visits to campgrounds, winter sport sites, wilderness areas, and other recreation sites continue to increase. As a consequence, many sites are overcrowded, subject to severe deterioration, and are becoming less conducive to quality recreational experiences. Resource managers are looking for ways to disperse visitors and even limit use in an effort to improve quality experiences and to protect sites from physical damage. Among the most common approaches either proposed or in use are reservation systems, referral systems, user fees, lottery systems, and outright user limits.

In a comprehensive study of reservation systems in use in the United States, Burnett (1972) found that only two of 23 systems were computerized and only the California State Park System was fully operational. To his list should be added the State of Virginia's computerized system. The Forest Service and National Park Service are planning to try out computerized systems in 1973. Most other systems are being used to administer group camping. Burnett (1972) found that reservation systems prove effective in reducing the impact of vandalism, maintenance costs, numbers of turnaways, site deterioration, and visitor conflicts associated with overcrowding. His study showed that use actually increased in California and Oregon Park Systems, but was distributed to more campgrounds in California. It also showed that entrance stations are needed for the successful operation of reservation systems.

Visitor acceptance of a reservation system is an important consideration to resource managers, but reports of public reaction are limited. Burnett reported a study by the Christian Science Monitor indicating that about 38 percent of the respondents suggested starting a reservation system for campgrounds. He also learned that resource managers had a "feeling" visitors were favorably disposed toward reservation systems, and that visitors at a national park in Colorado would favor such a system if it prevented overcrowding. But, Stong and Duke (1972) reported that 59 percent of the campers surveyed in the State of Washington did not prefer a reservation system for the State's parks. However, the respondents had little, if any, experience using a reservation system, which suggests the basis for comparing systems was weak. Nevertheless, dissatisfaction with a system's methods of operation may lead to public rejection. For example, Burnett found negative reactions by potential users because of the increased number of "no-shows" that cause sites to go vacant, the lack of vacancies after visitors had traveled long distances, and the lack of knowledge of a reservation system.

### REFERRAL SYSTEMS IN USE

Variations of a referral system are currently in use at several locations. The State of Oregon operates a campground information center that serves as a reservation and referral center. People can call or drop in and find out what facilities are available and be directed to them. At Jackson Hole, Wyoming, a radio

station broadcasts campground status reports to incoming tourists to help the national forests and parks direct campers to areas with vacancies. Yellowstone National Park uses radio and roadside signs for the same purpose. Some radio stations, such as those in Denver and Los Angeles, broadcast information on camp vacancies.

User fees are being used or planned in conjunction with most reservation systems. Their purpose is not to control use, however, because that would discriminate against low income groups. Rather, fees are charged to assure that users pay a greater share of campground costs than do nonusers. Lotteries offer another means for controlling use. Sometimes they are used, for example, to disperse hunting tags for certain game species where hunting is essential to maintain a limited number of animals in balance with their environment. However, the use of lotteries to limit recreational use is considered to be administratively unwieldy and could possibly lead to ticket scalping (Sharpe 1973).

Burnett (1972) has suggested that manual reservation systems may become unwieldy as the number of requests becomes very large. The State of Oregon manually handled only 47,000 requests in 1971 (Oregon Parks and Recreation Sect. 1971), whereas the State of California's computerized system handled about 98,000 during the same year (Meyer 1973). Recognizing the problem, large agencies such as the Forest Service and the National Park Service are directing their pilot programs toward computerized systems. Several companies have reservation systems or the capabilities for developing them, and undoubtedly more will join the competition.

Coordination of services is an essential part of any reservation system if public agencies are to eliminate the chaos that many visitors now face when forced to move from one full campground to another on the basis of recommendations offered by poorly informed campground managers. This is not to criticize the managers, but to point out the great need for effective regional and interagency systems that can successfully disperse campers to areas where facilities are available or warn them of "all full" conditions before they leave home.

## NATIONAL FORESTS

Even though a computerized reservation system has proved successful for making reservations for sports and entertainment attractions as well as for State park campgrounds, its usefulness to the national forests is not clearly defined. Individual State parks are usually closed systems with entrance gates and a resident staff. But national forest campgrounds are generally not designed and managed in such a manner. Entrance stations are practical at some campgrounds, but many others are not suited for such control. Therefore, it is desirable to investigate other means for dispersing use, compare them with the automated reservation system, and determine which system or combination of them may prove most useful on the national forests.

In addition, it may be valuable to develop a means for informing expected users that given areas are full, and redirect them to locations with vacancies. On key weekends, such as Labor Day, it would be desirable to warn people when areas are full and possibly encourage them to stay home. This suggests that a predictive model might be beneficial--a mathematical model that might tell, in advance, the approximate time when sites in key areas would be full. If such a model could be developed, it may then be possible to advise people not to leave home after a given time because all facilities would be at maximum capacity.

Historically, the Forest Service has told the public that the national forests are "theirs," as evident on highway signs and informational pieces that include such slogans as "Protect and Enjoy Your National Forest Heritage" or "The National Forests ...America's Playground." Some visitors may commence to doubt the "public" nature of the forests when they are faced with reservation requirements, user fees, and contact with commercial ticket vendors. Some may find the regimentation and mechanization objectionable. Others, on the other hand, will find the arrangements convenient and comforting in unfamiliar wildland situations. To some, a reservation system may seem unduly restrictive--even oppressive--especially those who like to roam and to be free of time schedules. Furthermore, a reservation

system may place some groups at a competitive disadvantage. People who cannot schedule their vacations well in advance may not be able to obtain a site when their vacation time is confirmed. Also, persons living in communities not served by a reservation system may be unaware of its existence or be less successful obtaining reservations by mail than persons who can make direct contact at a ticket office.

## TRIAL OF A RESERVATION SYSTEM

Commencing with the 1973 camping season, the Inyo and San Bernardino National Forests in California plan to make about 990 units available on 20 campgrounds by selling tickets throughout the State. The system proposed is similar to that used at California State Parks. It was developed and is administered by Ticketron, a company which pioneered in computer-controlled ticketing for entertainment and sporting events.

Briefly, the system operates in the following manner (Ticketron, Inc. 1972). The user decides when and where he would like to go camping. He contacts the nearest Ticketron outlet (usually in major department stores in suburban shopping centers or downtown areas) either in person or by mail. He asks if space is available at the place and time of his choice and specifies his party size and kind of equipment. If space is available, a ticket is issued for a registration fee of \$1.50 plus the daily campground fee for the number of days requested. Each ticket specifies the date and campground, but the camp unit is either indicated on the tickets or assigned upon arrival at the check station. Roving patrols are used to check tickets and direct campers where campground distribution and size make the use of check stations inefficient.

If a camper cannot obtain the camp of his choice, he is offered alternate days and size of units. Unfortunately, alternate campgrounds cannot be offered because a suitable computer program has not yet been designed to handle such cases. Ticketron is working on the problem, but until it is solved, campers must be prepared to suggest alternate campgrounds by using various campground directories.

A camper can cancel reservations and be refunded the campground fee. However, he forfeits the reservation fee, and in addition, pays an equivalent cancellation fee.

The period of advance reservation can be set according to agreement between Ticketron and the agency it is serving; e.g., 90 days for the State of California and 30 days for the Forest Service, at present. Ticket sales are stopped on Mondays for reservation periods commencing on the following Friday. Thus, the camper wishing to commence his stay on any Friday cannot make his reservation later than the previous Monday.

The Ticketron system provides nine reports that serve various accounting functions related to reservation status and sales. These reports allow agencies to control the reservation system and audit the entire operation.

The Ticketron system, as well as any other reservation or referral system, has shortcomings: (1) When campgrounds are filled to capacity, no statistics are provided concerning the number of parties turned away from ticket offices or campgrounds, the size of groups turned away, desired dates and lengths of stay, or facilities needed. (2) No information is provided concerning the subsequent action taken by turnaways; e.g., did they go camping? Where and when? (3) User or turnaway attitudes concerning the system are not sampled; e.g., do they feel too regimented? Do they like or dislike the system? etc.

Answers to such questions may suggest where new campgrounds are needed, which established campgrounds should be expanded, or explanations of why new development or expansion may not be possible. At a campground or recreation area controlled by entrance stations, the managers may not be concerned about turnaways since their numbers may rapidly diminish after users become aware that reservations are required. Such has been the case for the States of California (1971) and Virginia (Bolen 1973). However, campgrounds on the national forests are not all expected to be on the reservation system, and a large population of turnaways may continue to exist. Therefore, information concerning turnaways may prove useful for planning and administration.

## RESEARCH ON VISITOR DISPERSAL

Forest recreation researchers at the Pacific Southwest Forest and Range Experiment Station are seeking information that could help solve some of the problems associated with improving visitor dispersal on wildlands. Studies underway are aimed at (1) evaluating the reservation system being tested at California region campgrounds, and (2) developing information useful for deciding which systems or combinations are best suited to the national forests. The objectives of the research, roughly in order of priority, are:

1. Evaluate and compare existing and proposed automated and manual reservation systems, referral systems, and combinations of both.
2. Evaluate visitor reaction to the automated reservation system being tested on two national forests in California by using unobtrusive techniques and mail questionnaires.
3. Design a visitor dispersal system to inform the public of site availability, limitations, or closures and to feed back information about potential use to field locations. (Such a system is planned to serve regional and inter-agency needs.)
4. Determine how to assess the success or failure of diverting use away from overused to less used sites, predicting when given sites will be full, and stopping the influx of visitors when sites are full.
5. Determine which registration/referral system alternatives or variations of alternatives will prove useful for controlling use on wilderness areas, winter sport sites, organizational camps, and other areas subject to intensive uses.

## SYSTEM EVALUATION AND COMPARISON

Data will be collected for as many uniquely differing reservation and referral systems as can be identified. Each system will be analyzed individually and by making various combinations suited to agency capabilities and resource conditions. Factors to be considered may include, but not be limited to: a de-

scription of facilities, number and size of user parties, lengths of stay, kinds of equipment, visitor controls (area security and policing), turnaways, vandalism, fees (if any), personnel requirements, diversion of personnel from other jobs, public opinion, costs of operations (within limits of administrative cost accounting), visitor overflow (how much and how handled), and agency evaluations of systems.

Burnett (1972) found that eight States and one Federal agency operated reservation campgrounds using manually operated systems. Virginia has used an automated system; North Carolina and Pennsylvania are considering such systems (Bolen 1973). Information will be gathered to make comparisons between the manual and automated systems.

Reservation systems that are used by organizations such as hotel and motel chains, airlines, travel agencies, and commercial campground vendors will also be investigated. The logistics of such systems may differ from those required for campground reservation systems, but they would offer some useful ideas.

Referral systems are not so easily identified, but any that are functioning or proposed would be analyzed for their possible application.

## EVALUATION OF VISITOR REACTION

The California region's goal is to provide "a higher level of public service" by assuring users the availability of a campsite upon arrival at their destination and thus improving the level of their recreational experience. The Region believes its goal may best be achieved through evaluation of user preferences and opinions. The use of unobtrusive techniques and mail questionnaires seems feasible for obtaining the necessary data.

Two unobtrusive methods will be used. First, letters sent by users, turnaways, and others offering comments, criticism, or plaudits will be collected and analyzed. Second, oral comments, criticisms, or commendations by users or turnaways or both volunteered to or overheard by attendants, rangers, and receptionists will be recorded and analyzed. In addition, mail questionnaires will be used to uncover visitors' opinions about the system, determine how they learned about the sys-

tem, find out why people canceled or failed to show without canceling, uncover opinions of the reservation system as compared to previous experiences at non-reservation camps, determine difficulties encountered while making reservations, define groups that the system may discriminate against, and determine what happens to visitors that are turned away.

The National Park Service is planning to start computerizing reservation systems at six national parks, including Yosemite. The Forest Service has been in touch with the Park Service, and it may be possible to include the Yosemite operation in the Station's study. If an organization other than Ticketron is selected to operate the park's system, it will be desirable to assess their differences to determine which offers the greater service to the public and the Federal Government. Even if Ticketron is selected by the Park Service, it may prove worthwhile to determine if differences exist between visitors of the parks and the forests. No fundamental changes in the research design are foreseen in the event Yosemite is included in the study.

#### VISITOR DISPERSAL AND FEEDBACK

Comparisons of reservation/referral systems are expected to suggest a continuum of the most desirable to the least desirable individual or combination of visitor dispersal systems. Pure referral and combinations of reservation and referral systems may require considerable design and coordination input to make them functional.

A visitor dispersal system could be organized around public information centers located in major population centers, such as Los Angeles or San Francisco. Campground status information would be sent from ranger district and forest supervisor's offices to these centers. These centers would provide users with the names of campgrounds or recreation areas that are full, areas where vacancies exist, estimates of when sites are expected to be full, and "Recreation Visitor Alerts" that warn of areas that have filled or are filling faster than originally estimated.

The centers could be used to solicit and coordinate radio, television, and newspaper coverage of recreational site conditions. And the media could direct

reservation requests and questions to the centers.

Public information centers might be used to gather information from prospective users--particularly those that are referred to alternative sites, choose to defer their trip, or choose to cancel their plans altogether. Information to be gathered might include party size, desired date and length of stay, and kind of equipment. The data concerning potential site impact could then be sent to resource managers and used for decisionmaking and planning concerned with: expansion of existing facilities, construction of new facilities, limiting use where expansion or new development is not feasible, making estimates and requests for funding, recommending fee scales, reviewing special use permits to build commercial service facilities, designing new types of facilities, and developing public information programs to explain decisions.

Visitor dispersal and feedback systems should probably be automated since efficient visitor control may depend upon the speed with which information is transmitted from recreation areas to population centers. The study is expected to identify and assess means for quick, efficient, and economical transmission of information. Sources that may be considered, either individually or in combination, for designing the systems, include (a) existing national forest radio networks, (b) adaptations of the Ticketron system, (c) Campertron--electronic adaptation of radio and telephone nets (developed by Mike Levine, Inyo National Forest), (d) Federal Aviation Administration's air traffic control system, (e) other traffic control systems, and other reservation networks--hotels and motels, travel agencies, etc.

#### ASSESSMENT OF VISITOR DISPERSAL

The efficiency of any visitor dispersal system, be it a reservation or referral system, might be measured by the number of parties that can be diverted from one location to another, be persuaded to participate in an alternative recreational activity, or be persuaded to stay home. The study now underway will attempt to learn how to measure system efficiency, predict when sites are expected to be full, and stop user influx when maximum capacity is achieved.

We need to assess increases in visitation at underused sites as influenced by announcements at population centers that tell visitors where space is available. Simultaneously, it should be determined if such announcements tend to reduce the impact at overused sites. Point-of-origin data should also be collected to determine if people are coming from population centers where announcements were made, and control might be imposed by making announcements at specific urban areas but not at others. This is but one proposal; others will need to be developed and studied.

#### ADAPTATION TO OTHER LAND USES

The enormous growth in number of visitors to public lands is of concern to resource managers. Such intensive use is of particular concern in wilderness areas and at winter sport sites. Some form of user limitation or reservation system will likely be put into effect for wilderness use in the near future. Currently, users of wilderness areas in California are required to register before entering; they must specify the exact dates of use and locations to which they will travel. Managers at Sequoia-Kings Canyon National Park have been working with adjacent national forests and with Ticketron to determine the feasibility of a wilderness reservation system. Reservation systems are in use at many ski areas in the eastern United States, and within 10 years tickets may be needed to do any skiing in the West (Davis 1973).

The study will evaluate the possibility of adapting reservation/referral systems, developed for campgrounds, to the problem of limiting use on wilderness areas and other wildlands subject to excessive human impact.

#### CONCLUSIONS

Any reservation or dispersal system, with its attendant computerized mechanisms, ticketing, gatehouses, forms, and fees, inevitably brings urbanized life to the rural forest setting. People who leave the city to find a change in the wildlands are apt to discover that perhaps they experience less than they had anticipated. If the goal is to preserve wildland resources as places for enjoyment and changes from daily life styles, then the public

must accept some trade offs to avoid creating areas that are only reflections of urban living. Any system designed to disperse visitors or limit their number should be considered but one of several tools to be studied and applied. Whatever system is adopted, its aim should be to prevent the exploitation of wildland resources and to regulate use at a level that will protect the resource base--and still maintain the quality of recreational experiences.

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# MINORITY DEMAND FOR RESIDENT YOUTH CAMPING IN THE SOUTH

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**ABSTRACT.**--The recreation manager cannot afford to overlook minority preferences when he is estimating consumer demand. Minority demand is important in its own right, and it is important because of its impact upon demand of the majority. This paper describes black participation at resident youth camps in two Southern States, Alabama and Florida. Possible implications of increasing black participation are discussed.

## DIFFERENT PATTERNS

Many public recreation facilities such as parks, playgrounds, and beaches in the United States were established largely to serve underprivileged minorities, and use of some of these facilities by minority groups is very high. Use of other public facilities, however, is markedly less among nonwhites than whites. For a variety of reasons, including traditions, facility locations, and average incomes, recreation patterns of whites and nonwhites differ. This statement is not a lament and is not meant to suggest that nonwhite patterns are inferior. They may be just as beneficial and enjoyable as those of whites. It should be recognized simply that minority and majority recreation patterns are not alike.

Drawing from the 1965 Survey of Outdoor Recreation Activities, Deskins (1973) found that walking, picnicking, driving for pleasure, playing outdoor games and sports, sightseeing, and swimming, among a long list of activities, were enjoyed by the highest percentage of nonwhites. Water skiing, camping, hunting, and hiking on trails with packs were the least popular. A similarity in the ranking of the outdoor activities by whites and nonwhites ( $\rho = 0.93$ ) suggests that the difference is of degree rather than kind. In a regional analysis he found that nonwhite equalled or exceeded white participation in bicycling, fishing, walking for pleasure, picnicking, and sightseeing. In a survey of municipal recreation in New York City, Kraus (1970) found that Negroes dominated such activities as track and field, use of public swimming facilities, basketball, and several forms of combative activity, especially boxing.

Suppliers of recreation recognize the rights of minorities to public facilities,

but often wonder what types of services to supply. Today they are asking whether the new social climate of the United States will eliminate differences in recreation between whites and nonwhites, or whether the differences will persist.

Since my research in the last few years has centered on resident camping by minority youths, I will confine this paper to that area. The findings in this may, however, be applicable to other recreation situations.

## MINORITY CAMPING

Camp Pleasant, the oldest known camp for blacks, was founded in 1906 near Washington, D.C. (Jones 1927). It was established 50 years after the Nation's first youth camp, but at a time when camping was just becoming popular for young people (Gibson 1968). The purpose of Camp Pleasant was to provide an environment for developing good health habits and participating in outdoor recreation. Camping, however, has developed mainly among middle and upper-lower-class blacks and whites. And almost all those that attend camps are from cities.

Recognizing important values of camping, the President in 1967, called for camping opportunities for 100,000 disadvantaged youth. This figure was about 1 percent of enrollment in American Camping Association (ACA) camps. The ACA responded by saying that its members had surpassed that figure and would double it in 2 years.

My 1970 survey of resident youth camps in Alabama and Florida suggested that the black participation had increased markedly in just a few years.

Prior to 1964, the year the Supreme Court abolished segregation laws on the use of public facilities, blacks seeking

resident camping in Alabama generally attended all-black camps. In 1970, Alabama had three such camps that served approximately 1,500 youths. The first of these was established in 1926 near Birmingham largely through the efforts of a black nurse. By 1970, the number of nonwhites attending integrated camps was double the number attending the black camps. Almost one-half of the 71 camps in the State had at least one camper from a minority group. Nevertheless, the rate of camper participation remained low; only 7 percent of Alabama's 48,265 campers were nonwhite (Table 1). In face of new policies elsewhere, all-black camps are either closing or integrating.

Table 1.--*Reported and estimated camper numbers and participation rate in Florida and Alabama*

(In numbers)

Type of camper	Reported <sup>1/</sup>	Estimated <sup>2/</sup>	Participation rate/thousand
All campers:			
Florida	52,421	58,239	48
Alabama	48,265	48,265	68
Total	100,686	106,504	55
Black campers:			
Florida	8,137	8,884	35
Alabama	3,483	3,483	15
Total	11,620	12,367	26

<sup>1/</sup> 151 camps.

<sup>2/</sup> 162 camps.

The survey revealed only one all-black camp in Florida. It was established in 1952 by the Seventh Day Adventists and now accommodates over 240 youths. By 1970, the Scouts and other agencies had discontinued their separate camping operations for blacks and whites. A few religious and nearly all private camps had no minority attendance, but they represented less than one-fourth of the camps in the State. The estimated number of nonwhites in Florida resident camps was about 9,000 or almost three times that for Alabama. Moreover, the nonwhite camping rate of 35 per thousand persons of camping age was twice the rate of 15 for Alabama (Table 1). No doubt the more liberal interracial climate in Florida explains some of the differences.

## EFFECT OF MINORITY DEMAND ON MAJORITY

Surveyors of recreation are interested in the impact of black upon white participation at specific locations. Kraus (1970) reported that whites abandoned public pools once attendance by Negroes reach a certain percentage. In the camps in Alabama and Florida, there was a weak but significant negative relationship between camp demand and black participation. Camps with the largest black participation were least likely to be full. An increase in black campers of 1 percent was associated with 0.2 percent decrease in total demand when seven other independent variables were held constant. There are several possible implications of this finding. Integration may have dampened overall attendance, or camps suffering demand deficits may have more readily accepted nonwhite campers.

The overall rate of camping for Florida youth of 48 per thousand was unexpectedly lower than the rate of 68 for Alabama. The discrepancy was greater when white campers only were compared. This low rate in Florida may have been caused to some extent by integration. Employee cutbacks in the space industry and other economic factors are believed to have entered the picture too. Stevenson in his study of ACA camps in the South found that a fear of an overall drop in demand was one of the main reasons cited by camp directors (mainly of private camps) for not admitting campers of all races.<sup>1</sup>

Resident youth camping among blacks appears to be increasing now that restrictions have been lowered. In other words, availability and accessibility have bred demand. The increase may indicate that ethnic differences in recreation patterns will not persist in a liberal climate.

But, paradoxically, increased activity by minorities may reduce majority participation. In some cases there may be a "tipping point," a certain percentage of minority participation that triggers a rejection of a facility by the majority. Not enough is known about this process in

<sup>1</sup>Personal communication with John Stevenson of Clemson University who surveyed camps registered with the American Camping Association on their attitudes toward the ACA interfaith-interracial policy.

recreation to justify speculation about particular percentages. Certainly models predicting demand for specific resources should consider the dampening effect of minority demand. At the same time that minority participation is encouraged, thought should be given to maintaining majority attendance.

Since the supply of outdoor recreation facilities is getting scarcer, denial of public facilities to certain groups is indefensible. The greatest number will receive the greatest good in the long run if participation by all groups is encouraged and intergroup harmony is actively promoted.

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## INTERPRETATION TO INCREASE BENEFITS FOR RECREATIONISTS

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**ABSTRACT.**--To be effective, interpretation must attract and hold attention. For greatest interest, interpretation must be dynamic, rewarding to visitors, easily obtained, tailored to diverse visitors, and meaningfully structured. Evaluation of effectiveness requires feedback from visitors and objectives for which achievement can be measured.

By training, most resource managers are applied ecologists who have a wealth of special insights to share with people. This is important now that "ecology" is a household word. But, instead of being recognized as the good guys in the white hats, resource managers are increasingly thought of as villains. There are many reasons for this, one of which concerns our communication skills.

Before plunging into the how-to-do-it aspects of interpretation, we need to consider "What is interpretation?" and "Why should we bother ourselves with it?" Interpretation means the translation of information into understandable terms. In settings used by recreationists, interpretation refers to all the procedures used to make natural and cultural history understandable and enjoyable. Typical examples are campfire programs, guided walks, nature trails, exhibits, and visitor centers.

Why is this our concern? Why should we interpret the areas used by outdoor recreationists? To answer, we must examine our reasons for undertaking resource management of any kind.

No matter what the activity, we find that one overriding goal ties together all the diverse activities of resource management. This goal is to provide a sustained flow of benefits for people. Even private ownership and the search for profit are ultimately tied to a philosophy of promoting and sustaining the common good. We need to remember that wood, water, wildlife, recreation, and other land products are not ends in themselves but are means to the end of providing people with a sustained flow of benefits. Recreation experiences are "products" and thus benefits just as much as logs or other commodities.

This matter of benefits provides the first of four basic reasons for offering interpretation.

1. *By interpreting the areas we administer, we can directly enhance the experiences of our visitors and thereby increase the flow of benefits provided by such areas.* By enriching visitor experiences, interpretation can increase the production of benefits without an increased impact upon resources. The matter of benefits also provides a second reason for offering interpretation.

2. *Our continued tenure as land managers depends on our ability to provide people with many kinds of benefits.* Over the years, lands have continually been taken away from agencies concerned mostly with material products and have been transferred to agencies concerned primarily with experiences. If, on the basis of oversight or a utilitarian tradition, we ignore many values and default in making resources yield the full measure of benefits for which they are suited, then someone else may replace us.

3. *Interpretation can increase the effectiveness of resource management.* Informed visitors are likely to use resources with less damage than uninformed visitors. In addition, interpretation can be used to attract people to the areas suited for use and away from the areas that are overused or unsuited for heavy use.

4. *It is increasingly important to help people understand the dynamics of the natural environment and the consequences of their actions.* As all demands upon resources increase, the choices become more complex and difficult. At the same time, public participation in resource decisions is increasingly common, making an understanding of natural systems even more important for responsible citizenship.

Having considered what interpretation is and why it is important, we're ready to see what research can tell us about doing a better job. In the few studies addressed specifically to interpretation--and in the overwhelming amount of related research from such fields as education, communications, and psychology--three major points stand out. *The first is that any message must attract and hold the attention of the person for whom it is intended. Otherwise, he will simply ignore it. Second, we need clear objectives that define what we are trying to accomplish. And third, some means of feedback is essential to show how well objectives are being achieved. Otherwise, we have no way of knowing the effectiveness of interpretation.*

### ATTRACTING ATTENTION

Unless we attract the visitor's attention, interpretation cannot be effective. An obvious first step in gaining attention is to provide interpretation where the visitors are. Yet this is not always done. Visitor centers, for example, are sometimes built out of view or even miles away from heavily traveled roads.

Sometimes interpretation is given where visitors will not stop or notice it. For example, at the Marine Science Center in Oregon, excellent exhibits are largely ignored because they are on walls *behind* visitors who are watching the live fish. To reach people, interpretation must be offered at such times and places and with such publicity that it is easy for them to use.

A number of introductory techniques are useful for gaining visitor attention (Boulanger and Smith 1973). One is to offer valuable knowledge or skills. For example, a presentation might begin with "What would you do if, while hiking, you met a bear with two cubs?" Or, it might begin with a discrepant or seemingly self-contradictory statement that arouses curiosity and requires explanation. For example, "This forest was created by a forest fire," or "The nearest formation of rock like this boulder is over 50 miles away." TV ads are full of discrepant events used for attracting attention.

### HOLDING ATTENTION

To hold visitor attention, interpretation must be interesting. Interest depends on both the subject matter and the way it is presented. In a study of exhibits, we

found higher visitor interest in violence and violent events than any other subject category (Washburne and Wagar 1972). This is nothing new. Plays and myths dating back thousands of years show that storytellers and entertainers have probably always known that violence is interesting. Fortunately, natural environments abound in violent stories that can be told in good taste.

Although such subject categories as violence, animals, and ecological relationships are predictably interesting, many visitors to interpretive programs are not seeking information, as such. Instead, they are often engaged in an open-minded search for new and enjoyable experiences. This often makes the pattern of presentation more important than the specific subject matter.

For greatest interest, interpretation must be dynamic, rewarding, and easy on the visitor. Other things equal, person-to-person interpretation is best and unmanned presentations need the same qualities. In our study of four visitor centers, we found visitor interest to be greatest for dynamic presentations that included such things as motion, recorded sound, and shifting lighting (Washburne and Wagar 1972). In contrast, interest was lowest for inert presentations involving mounted photos and written labels. Yet such "flatwork" exhibits are probably the commonest of all. The contrast between dynamic and inert is also very close to the contrast between the media used for entertainment (usually rewarding) and those used for education (often uncomfortable) (Washburne and Wagar 1972; Travers 1967).

The reward or payoff provided by interpretation is crucial for effectiveness. Too often, however, we become so concerned with the payoff to ourselves that we overlook the payoff for our visitors. As a result, we often concentrate on what we want people to know rather than why they would enjoy knowing it.

Rewards can take many forms. For the visitor who is already motivated to want information, such information is rewarding all by itself. Other visitors need a much larger "vehicle" of entertainment with a much smaller "load" of information. For example, at Disneyland, the Journey Through Inner Space was developed on behalf of a corporation at an enormous cost. Yet the visitor's experience of penetrating first a snowflake, then a molecular lattice, and even an atom within an ice crystal is almost

pure entertainment. Toward the end of the experience the visitor is told only the name of the corporation, the fact that it is in the business of rearranging molecules, and that he may see a few of the company's products on the way out if he chooses.

Psychologists have found that getting the right answer to a question is rewarding (Deterline 1962). This is the basis for teaching machines and programmed instruction. As one application of this, we developed a programmed nature trail in which visitors were asked a question at the bottom of each sign and then given the right answer on the next sign.<sup>1</sup> Children remembered more from these question-and-answer signs than from the usual signs.

One of the most rewarding things is simply having an effect when you do something. In one study, we built a recording quizboard on which visitors answer four questions by pushing buttons (Wagar 1972). Each time a correct button is pushed, a "correct answer" panel lights up and the visitor is presented with the next question. The quizboard--as the only exhibit in the building that could be manipulated--became a favorite exhibit for children the moment we installed it.

The rewards of interpretation may be appropriate ends in themselves. But if rewards are intended as means for increasing visitor understanding, then they must be carefully used so they help instead of hinder. For example, at the Chicago Museum of Science and Industry, most of the exhibits provide for visitor participation. But the day I visited, school groups were running about almost randomly twisting knobs, pushing buttons, and yanking handles but paying little attention to content. For best results we must make rewards contingent on learning or performing.

For interpretation to hold visitor attention, the rewards it offers must be worth the effort required from the visitor. This often requires making interpretation easy as well as rewarding for people. Making interpretation easy involves the use of symbols, tailoring presentations to the audience, and providing meaningful structure.

Messages are usually made of words, which are symbols. The words or other symbols used must be those the audience understands.<sup>2</sup> As an extreme case, a talk given in Chinese will not be understandable to most Americans. For greatest effectiveness, use words that fit the visitor's vocabulary. Also, use examples and analogies that draw upon things he has experienced. Often a few carefully chosen words can draw forth rich sensory memories that are shared by most members of your audience. How many of you, for example, remember specific places and occasions with the phrase "the sudden tug of a fish taking the bait"? If you draw upon the visitor's memory, his mind can supply thousands of times as much information as the words you used to trigger his thoughts.

Readability is important. In general, short sentences with little words are easier to understand than long sentences with big words. Formulas to determine levels of "readability" have been available for many years (Flesch 1949). However, Hunt and Brown found much of the interpretive material they sampled to be very difficult reading (Hunt and Brown 1971).

For people on vacation, reading may not seem worth the effort. At Yellowstone, for example, McDonald found that only about 10 percent of the visitors stopped at the wayside exhibits and less than half of them read the signs.<sup>3</sup>

Listening is easier than reading, and recorded sound has been associated with high visitor interest in several studies (Washburne and Wagar 1972; Mahaffey 1969; Erskine 1964).<sup>1</sup> For recorded sound, as with a real live interpreter, visitors can listen to information without looking away from main attractions. Also, substantial amounts of rather detailed information can be presented without visitor fatigue. If desirable, sound effects and dialog can be used to provide realism or drama.

In a study on a nature trail, we found cassette tape players to be extremely well received, especially when we kept the length down to 16 minutes for the 12 stations.<sup>1</sup>

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<sup>2</sup>Ronald E. Dick, David T. McKee, and J. Alan Wagar. A summary of major principles from communications and related fields. (Manuscript in preparation).

<sup>1</sup>J. Alan Wagar. *Evaluating interpretation and interpretive media*. Paper presented April 7, 1972, to Assoc. of Interpretive Nat., Pine Mountain, Georgia. 14 p.

<sup>3</sup>Arthur L. McDonald. *Final report to the National Park Service, Yellowstone Park*. 35 p. 1969.

For a 22-minute tape, a few visitors said the pace was too slow and that they would prefer a booklet permitting them to scan quickly to the information they wanted without waiting for it on tape.

Too often, interpretation is aimed at the nonexistent "average" visitor (Field and Wagar, in press). Tapes, for example, can be developed for different languages, interests, age or educational levels, or for visitors who want to spend different amounts of time. Additional groups to consider include families, local residents, and repeat visitors. Additional factors to consider in matching interpretation to different groups include levels of information and information needed before additional ideas can be understood (Boulanger and Smith 1973). For example, visitors cannot understand how a geyser works unless they already know that the boiling point of water changes with pressure.

A final factor to consider, if interpretation is to hold visitor attention, is structure. Visitors need some sort of framework to make information fit together meaningfully. In studying four visitor centers, we found that visitors were more interested in holistic than fragmented presentations. Thus exhibits that had parts making a whole story and that gave cause-and-effect relationships received greater visitor interest than exhibits that provided only isolated facts, such as the identification of species (Washburne and Wagar 1972).

As another example of structure, Screven, in his studies at the Milwaukee Public Museum (Screven 1969), found that visitors who were given a "pretest" to find out what they knew before seeing an exhibit remembered more from the exhibit than visitors who received no pretest.<sup>4</sup> Apparently the pretest gave them an outline of the things to look for. This suggests giving visitors an overview to orient them at the beginning of an interpretive presentation.

Orientation and focusing can also be provided within a presentation. One of our cassette tapes for a nature trail asked periodic questions of the visitor. This focused the visitor's attention and increased his retention of the information asked about. However, it *decreased* retention of information given just before and after a question.

At the Pacific Science Center, in Seattle, cartoon story lines are used to tie science stories together until youngsters learn enough concepts to handle a more scientific structure.<sup>5</sup> The cartoon stories serve another useful purpose. The person giving a demonstration often asks youngster what would happen if the cartoon character took a given action. If a youngster gives a wrong answer, it's the cartoon character's problem, not his own. This "projective" technique saves the child's ego enough that he'll go right on volunteering answers without embarrassment.

Other methods of giving structure to a presentation include proceeding from the simple to complex, proceeding from the whole to the parts, presenting a chronological development, progressing from the familiar to unfamiliar, moving from the seen to unseen, and showing increasingly broad application of a principle (Boulanger and Smith 1973).

## OBJECTIVES

Although the various techniques for gaining and holding visitor attention are vital for effective interpretation, they do not specify what it is we're trying to accomplish. For this, we need objectives.

A problem with objectives for interpretation has been to make them specific enough to provide a basis for evaluating and improving effectiveness. Usually they are stated as broad goals; for example, "Interpret the natural and scenic attractions of Horsethief Valley," or "Enrich the visitor's experience during his visit to Badger Flats." Although such broad goals serve as useful policy statements, they provide no yardsticks against which to measure achievement. How do you know when the attractions of Horsethief Valley have been effectively interpreted?

We can solve part of the problem by borrowing the idea of behavioral objectives from the educators (Mager 1962). Behavioral objectives specify what a student, or visitor, should be able to do as a result of a presentation. An example would be, "After hearing the nature talk at Horsethief Valley, the visitor should be able to name and describe the three major forces that shaped the valley." Such objectives provide a basis for measuring effectiveness.

To gain the advantages of broad policy goals as well as very specific behavioral objectives, we can develop a pyramid or

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<sup>4</sup>C. G. Screven. *Personal communication*, 1970.

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<sup>5</sup>Jerry Dotson. *Personal communication*, 1970.

hierarchy of objectives (Putney and Wagar 1973). In this, each broad policy goal must be supported by one or more layers of specific objectives which, if achieved, contribute toward accomplishment of that policy goal. For example, a broad policy goal might be "Show visitors the positive and negative effects of environmental modification."

One of several more specific objectives that are consistent with this goal might be "Show visitors the interrelatedness of the parts of an ecosystem." Such an objective is specific enough to provide a basis for selecting among the interpretive opportunities available.

If, within the planning area, a salmon stream is judged to provide the most suitable opportunity for showing the interrelatedness of ecosystem parts, then a number of very specific behavioral objectives can be developed to specify what visitors should be able to do on the basis of the interpretation. Such objectives might include, "Enable visitors to describe the life cycle of the Pacific salmon, conditions necessary for survival of the eggs and young fish, and human activities that can upset these conditions."

#### FEEDBACK

As soon as interpreters are thinking in terms of very specific objectives, then feedback and evaluation can be built right into interpretive programs--something that has seldom been done. A great deal of feedback is available informally, as interpreters watch their audiences, listen to questions asked, and look for other evidence of interest, enjoyment, puzzlement, and so on. In fact, such continuous feedback is a major advantage of person-to-person presentations. However, informal feedback can be misleading. Because many visitors are polite enough to compliment an interpreter for a bad program, any bad habits he may have are reinforced. Informal feedback therefore needs to be supplemented with more formal methods.

One approach is to use interviews or questionnaires to determine how well visitors are enjoying and remembering. A second approach is to provide games or self-testing devices such as the recording quizboard (Wagar 1972). These record numbers of right and wrong answers and provide a basis for evaluating changes in a presentation. Currently we are working toward observational techniques for determining audience interest and interactive audiovisual presentations

that ask questions and record answers as well as tell a story.

An additional phase of feedback and evaluation is to determine cost per visitor contact or perhaps some other unit of visitor participation.<sup>6</sup> This requires records for both costs and attendance. In a study of visitor contact facilities in the Black Hills National Forest, we found a wide range of costs per contact. We also found that nobody knew the cost per contact for various alternatives. Yet without this kind of information, cost-effectiveness cannot be defined.

In summary, interpretation offers a way of increasing the benefits provided by our natural resources. For greatest effectiveness in interpretation, we need to make it rewarding for people; we need clear objectives; and we need feedback and evaluation to tell us how well objectives are being achieved.

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## MARKET RESEARCH--THE MISSING LINK IN RESOURCE-DEVELOPMENT PLANNING FOR OUTDOOR RECREATION

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**ABSTRACT.**--The development of progressive models of outdoor recreation markets is described, with emphasis on research findings from the family camping market. An introductory stages-of-growth model is presented in stages: infancy, adolescence, young adulthood, and maturity. From this, a more complete model of camping market expansion is developed, which details the sizes of and relationships among various segments of the camping market, potential, active, and inactive. A final comprehensive model ties together the concepts of market expansion and market development. Implications for management, research, and recreation resource planning are described for each stage of market growth.

### THE "CHAOS OF CONFUSION"

Grodzins (1962) described outdoor recreation as a "chaos of confusion" as he viewed the multiplicity of agencies, missions, and jurisdictions that have a finger in the outdoor recreation pie. He concluded that the virtues of chaos, such as inter-agency competition, are far more desirable than the hazards of orderliness and the immense power that accompanies it. Significantly, Grodzins' impressions of chaos date from his 1962 examination of Federal agency involvement in outdoor recreation before the days of a Bureau of Outdoor Recreation, all-terrain recreational vehicles, environmental impact statements, snowmobiles, over 4 million camping vehicles on the road, standing-room-only wildernesses, \$25,000 motor homes, and a commercial sector of recreation developments that dwarfs the combined involvement of all levels of government.

In listing the merits of a confused and chaotic state, Grodzins completely missed one of its greatest virtues: scientific appeal. There is a strong and fundamental scientific appeal to ordering disordered states. My objective is to try to chart an orderly path through the maze of industry propaganda and emotional pronouncements about the opportunities and threats of growing outdoor recreation markets.

My basic premises are: (1) that most outdoor recreation activities can be studied usefully in the context of a market; that is, buyers and sellers conducting marketplace transactions in an environment of close substitutes, (2) that most decisions by consumers of outdoor recreation goods and services take place in relatively typical market sit-

uations. For example, the selection of a campground after arriving at a regional tourist attraction, the purchase of a seasonal skiing pass, and even the mail-order selection of a wilderness visit among competing sets of wilderness trail ride offers, (3) that market research, which is essentially a kit of tools for reducing risk in management decisions, has some potential for improving the state of public and private outdoor recreation planning, and (4) that risk in management decisions can be related to dollars in order to determine how much to invest in research for any given market situation.

The subject matter of market research can be classified broadly into two reasonably distinct areas:

Marketing research includes informal "in-store" experiments along with comparisons of the effectiveness of different types, exposures, and content of advertising appeals; also more formal studies of consumer preferences, buying habits, and the testing of various marketing theories such as brand loyalty and impulse buying.

Market structure research focuses on such phenomena as trends in the size and geographic distribution of firms in a market, product differentiation, shifting market shares, and industry growth rates.

Ideally, these two types of research should complement each other. In outdoor recreation research they do not. We have produced an abundance of consumer studies, but have developed no logical market framework to tie them to. Recently, in examin-

ing camper surveys to develop an annotated bibliography, I found that there are hundreds of studies about campers, but that hard data about campground numbers, occupancy rates, and the general state of the campground industry are nearly impossible to find.

The fact that we have hundreds of consumer surveys and no generalized market model by which to interpret them is probably related to many of the embarrassing situations that outdoor recreation management and research finds itself in today. For example, we seem to know quite a bit about skiers, but we know so little about the state of the skier market that we have moratoriums on further ski area development in some of our prime skiing country in the Northeast. We apparently know a great deal about campers, but we know so little about the camping market that at least one campground trade association would like to see legislation enacted requiring the filing of an "economic impact statement" before development of new campground facilities on public lands. And, of course, for all our consumer research of the past 10 years, we can still do no better job of forecasting recreation demands than we did in the early 1960's.

#### A STAGES-OF-GROWTH MODEL

The growth of a market over time follows the pattern of a generalized growth curve just as the growth of a population does, or the growth of any biological organism. So the analogy of human growth stages to the growth of a recreation industry is very appropriate (Peterson 1971). Figure 1 depicts a generalized growth curve and identifies segments of that curve as five broad stages of growth: infancy, adolescence, young adulthood, maturity, and senility.

There are many ways that a generalized model such as Figure 1 can be useful without any further refinement of the growth stages. For example, it is possible to study available industry growth rates and to arbitrarily place many recreation markets within different stages on the curve. Hunting, its growth approximately equal to the rate of population expansion, could be termed a mature recreation market; all-terrain recreation vehicles, with growth rates of 5 to 10 times that of the population, represent an adolescent market. An adolescent market is one that is highly responsive to mass advertising appeals.

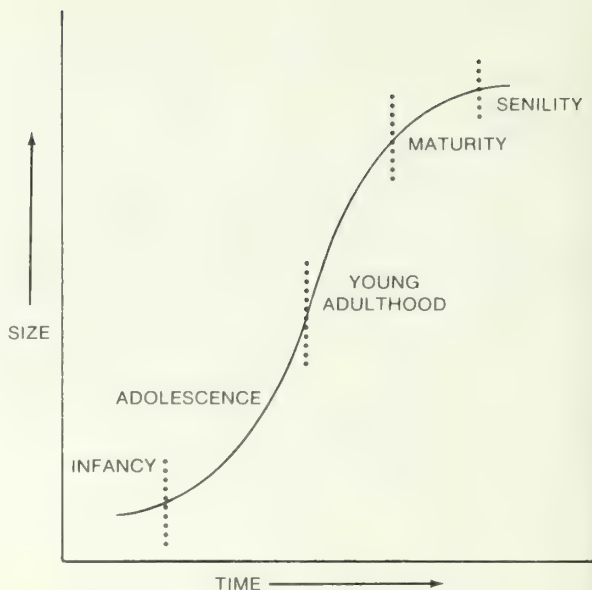


Figure 1.--A general model of a recreation market growth curve, with arbitrary placement of five broad stages of market growth. Measures of "size" along the Y axis can be in any specified terms, dollars invested, units of production, numbers of enterprises, capacity, or numbers of campers, skiers, visitor-days, etc.

Clearly, if indices of growth--population expansion and per-capita increases in travel, income, and leisure--are drawn from a mature economy and used to derive coefficients of expansion for recreation markets that are in stages of adolescence and young adulthood, demand predictions will fall far short of their true potential. And, of course, this is exactly what has happened to most of our attempts to predict recreation demand.

The utility of a stages-of-growth model can be enhanced much further if accepted definitions of each growth stage are available, making it possible to be less arbitrary in locating the relative positions of various outdoor recreation markets. To this end, the following provisional descriptions of the first four stages are offered. No attempt is made to describe the fifth stage (senility); its occurrence will be rare because of the immense marketing and technological investments that mature recreation industries will expend in order to recycle the market into a more vigorous growth stage.

### Stage 1--Infancy

This is a period of extreme inefficiency in such areas as buying power, merchandising, and communications. This growth stage is characterized by a large number of entrepreneurs, all having a good idea at about the same time. They recognize an apparent demand for something like commercially developed campsites because they may be in a position to see an increasing incidence of capacity crowds at public parks. But they have little capital to develop an enterprise. And, because the industry is new, their available sources of borrowing are limited. There is little variety and diversity in the types of developments and services offered to the public. Management and marketing are largely matters of trial and error because of a lack of experience and lack of knowledge of the market.

Infancy, at least in commercial recreation developments, is also a period when the majority of enterprises are located on land already owned by the developer. In many instances, the owner may have been looking for some type of development that would help him to pay the taxes and retain ownership. Individual enterprises have relatively little awareness of each other and practically no communication with each other. There is little public concern about the industry in terms of a need to control, license, register, or set standards. Research is almost nonexistent.

### Stage 2--Adolescence

Exact boundaries between growth stages are meaningless. But at some point, an industry begins to develop very rapid growth in number of enterprises. The growth of recreational vehicle manufacturers and the growth of commercial campgrounds followed parallel patterns. In this stage, enterprises have larger capacities and bigger financial investments. The average investment per enterprise in stage 2 may be 5 or 10 times that of stage 1. Individual enterprises begin to become more business oriented; they are more concerned with early returns rather than with building a retirement nest egg. Campgrounds during stage 2 began to have full-time managers. Sources of venture capital open up as risks begin to become well established. This is the period of experimentation with new forms of management: associations, affiliations, and franchises. Developments in stage 2 are often on land that was purchased because of its ideal market location. Trade

associations emerge, strengthen, and begin to become involved in such things as communications, standard setting, and collective buying.

Coincident with the growing importance of communication within the industry, research becomes a dominant value and takes the form of feasibility studies, economic analyses, and preliminary attempts to identify trends in growth. Established corporations, looking for opportunities to diversify, conduct some market studies on their own and establish a few pilot projects, or experimental developments.

### Stage 3--Young Adulthood

This is a preliminary shakedown period for the industry. Many of the stage 1 Ma-and-Pa type enterprises can no longer compete in the market and disappear from view. In short, there is a gradual shifting in market shares toward the larger and more efficient operations. There is a noticeable shift in the size distribution of firms in the market. The period of phenomenal growth may be over, but a sustained period of impressive growth rates may remain.

During stage 3, the value of market information becomes well established. Many enterprises begin to contract their own research or even set up their own research branches. At the same time that information is becoming an important satellite industry, many established information sources begin to dry up as industry leaders are increasingly reluctant to share the knowledge that may give them a competitive edge.

Toward the middle of stage 3, a shift in trade association activities toward lobbying may become evident. This is not simply a response to the growing level of industry secrecy, but may also reflect a direct response to increasing public concern for needed legislation and social control of a potentially powerful industry.

### Stage 4--Maturity

Growth, in terms of new enterprises, drops to the level of or below the rate of population expansion. Expansion of existing enterprises may continue as a favored form of competition. The market becomes dominated by a smaller number of large concerns and trade associations. Growth of individual enterprises takes place at the expense of other enterprises. Broad industry-wide promotions are more frequently aimed at increasing the spending of people who are already in the market as opposed to

earlier efforts to expand the size of the market.

In stage 4, research becomes "intelligence," and most enterprises now buy their own and guard it closely. The research focus is on ways to delay further market maturity through technology, equipment innovations, improved marketing appeals, and second guessing the competition. Broadly sponsored market studies, and those conducted by public agencies, take the form of statistical reporting.

Trade associations in a mature market, except in times of a threat of outside interference, may take on an almost symbolic country club role, providing sources of enhanced prestige for industry leaders.

#### A TEST OF THE MODEL: THE CAMPING MARKET

Research plays a markedly different role in each of the growth stages. In theory, we could determine the relative growth stage of a market by the type of research attention that it is receiving. However, a comprehensive examination of the total research effort is rarely possible because of poor communication systems in the industry's early stages and secrecy in the later stages.

A consistent role of research throughout the growth process is to monitor market growth in order to identify the stage, and even substage, that the market is currently in. This type of knowledge has obvious implications for the timing and location of new developments, for determining appropriate marketing strategy and for effectively predicting short-term demands.

Even with complete agreement on the growth stage descriptions, it is practically impossible to locate the camping market more precisely than somewhere between late stage 2 and early stage 4. Additional information is needed. And it is usually available from a variety of sources. Existing consumer studies may provide some clues to current market stage; historical analyses of the growth rates of the market's component industries can provide further clues; and the generation of new information may be required if the need is great enough. Some very brief examples of each type of research, drawn from a recent examination of the camping market, may be useful.

#### Analysis of Available Camper Surveys

The large number of available camper surveys, dating from the late 1950's, pro-

vides a rich (though often frustrating) source of information about possible trends in camping. For example, it is often possible to make gross comparisons between the findings of recent camper surveys and older studies of items such as: (1) the percentage of campers who have just begun to camp, (2) the relative proportions of tenters and vehicle users, (3) the average level of annual camping participation, and (4) investments in camping equipment.

From such an analysis we might conclude that numbers of campers and their equipment investments are increasing, but that average levels of camping participation may be decreasing. Such a finding could indicate that the market is still in a relatively young growth stage and that it is adding new participants faster than the available supply of campsites can accommodate them. The result is that something has to give, namely the number of days of camping per year. Such an observation might even be reinforced by a historical examination of campers' comments in regard to "crowding," "difficulty in finding available campsites," and "the increasing need for reserving a campsite before leaving home."

#### Growth Rates of Component Industries

Although this may be the weakest, and often most biased, source of market data, published information is generally available about growth trends in the several component and service industries of a recreation market. For example, it is not particularly difficult to obtain information about the number of companies publishing campground guidebooks and camping magazines (both public and trade journals) and their circulation figures. Production figures for recreational vehicles are available on an annual basis. The number (now over 50) and size of campground franchising organizations is probably an important indicator of market growth; so is the number and membership of campground trade associations. And the number of commercial campgrounds, and their capacities, can be dug out of licensing bureau records and from past censuses and surveys in some States.

A recent examination of the commercial camping market in New Hampshire (LaPage *et al.* 1972) disclosed that the number of camping enterprises in that State doubled every 3 years from 1955 to 1964. The next doubling did not occur for 8 years, until 1972. A similar slowdown in the production statistics issued by the Recreation Vehicle Insti-

tute is evident. Both trends reflect a normal pattern of growth that would be expected from our knowledge of the growth curve. But they do serve to suggest that the camping market is out of the phenomenal growth period of stage 2 and well into stage 3.

#### Generation of Original Information

At this point, the need for new information may become critical to many investors in the market. If, in fact, our analysis is correct and the camping market is well into stage 3, this means that a distinct slowdown in growth (stage 4) may not be too far away. Many industry leaders would now like to know how much room for market expansion is left?

However, that question cannot be answered by any source of available data because all research up to this point has concentrated upon the growth of the active camping market and not upon the concurrent shrinkage of the potential camping market. (The physical law of equal and opposite reactions works on markets too!) In an attempt to answer this question, the Forest Service, in cooperation with several industry leaders, recently conducted a national survey of the camping market's potential for future expansion.

This national survey (LaPage 1973), in addition to providing some estimates of growth potential, also served as a means of validating the apparent trends that are evident in several regional and local camper surveys. And, although these smaller surveys are seldom strictly comparable in methodology, dates, and market segment focus, we found that the national survey confirmed such observations as a decline in average camping rates, shifts in camping styles, and an increase in complaints about campground conditions, notably crowding.

#### EXPANDING THE MODEL

As research generates new information and is able to integrate it successfully with the information that has been lying on the shelf collecting dust, another important role of the market analyst emerges--that of model builder. Starting with a very simple but useful growth-curve model, it is now possible to expand that model into a comprehensive model of the entire camping market system. The advantages of a system model over the simple stages of a growth model come from being able to understand how all of the various market segments are interrelated and influence each other.

The first step in graduating the growth model into a system model comes with the realization that, as the active camping market expands, its reservoir for future growth (the potential camping market) shrinks. In simplest terms, this can be viewed as the area above the growth curve being compressed as the area below that curve expands. However, a more useful and realistic model is presented in Figure 2, in which prospective campers move through various stages of potential from a low to a high propensity to try camping. Similarly, after those with a high potential become campers, they move through a series of stages toward permanent camping inactivity to complete the cycle.

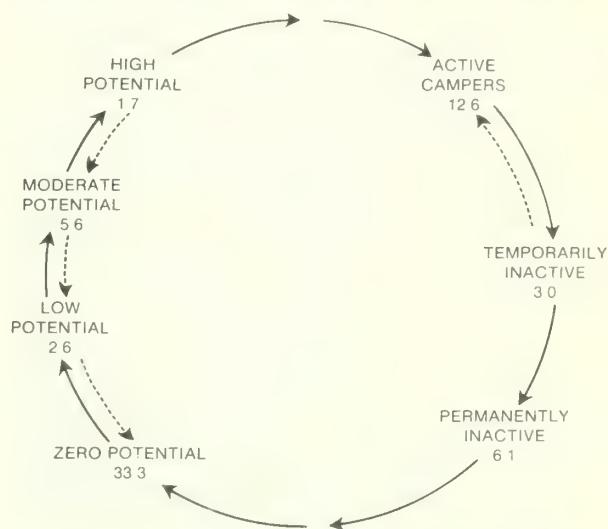


Figure 2.--A model of camping market expansion, showing the approximate sizes of various market segments (in millions of households). Based on a 1971 national survey of 2,003 households, conducted by Opinion Research Corp. Note the possibility of flow reversals (dotted lines) among certain segments of the potential and developed camping markets.

Through the results of our national camper market survey (LaPage 1973), we have been able to place figures on each of these steps in the cycle in terms of millions of households. And through continued research, we will be able to estimate rates of flow between the various segments of this system and also learn how those rates may be affected by mass advertising and other marketing appeals.

The recognition that there is a dynamic cycle of involvement in the camping market

leads to two added, and critically important, components of that cycle (Fig. 3). The first of these components is a *drive* or *control mechanism* which can speed up or slow down the rate of movement through the cycle. This control mechanism, itself a complicated system, is labeled simply "advertising." In fact, it is all of the varieties of mass persuasion, social pressures, and market promotions that are used to encourage new sales.

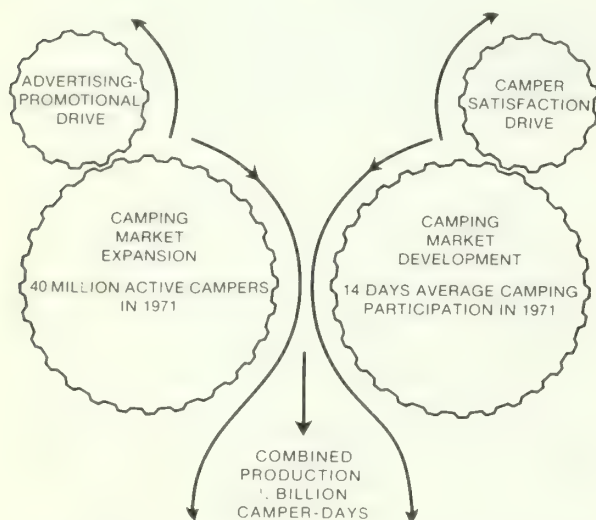


Figure 3.--A model of camping market growth, showing how market expansion and market development combined to produce 1/2 billion camper-days (in 1971). The left side of this model is presented in greater detail in Figure 1.

The second essential component--to complete the market model--is based on the concept of an *efficient rate* at which this cycle of market expansion should operate. That is, the camping market should not be expanded, through the efforts of its control mechanism, at a rate that cannot be matched by the ability of its component industries to provide thoroughly satisfying camping experiences. For example, if the number and diverse interests of new campers who are encouraged to enter the market exceeds the number, quality, variety, and geographic distribution, of available campsites, the camping cycle will speed up, campers will be dissatisfied, and many will become inactive after a year or two instead of staying in the camping market for a much longer period of time.

If the camping market expands much faster than facilities are developed, several results

can be predicted. First, with rising dissatisfaction, campers will begin to camp less, the average rate of camping participation will decline, and that decline may offset whatever gains are achieved through market expansion and costly promotions. In addition to declining participation rates and increasing market dropout rates, camper dissatisfaction may be expressed in other ways such as purchasing land for a personal campsite, or otherwise changing camping styles. Campers may continue camping just as much, but in avoiding the crowds and waiting lines at public campsites they also eliminate much of their former economic impact.

Since all these effects seem too evident today--a rapidly expanding inactive segment of the camping market and a steady decline in camping frequencies--we can conclude that the two halves of the camping market, expansion and development, are not operating efficiently.

#### IMPLICATIONS FOR MANAGEMENT

Any improvement in understanding recreation markets, their growth curves, and their market systems, will present opportunities for alert administrators--through better timing of their development planning, through more appropriate marketing strategies, and through the correction of sources of consumer dissatisfaction. However, the really significant implication of the research and model building that I have described lies in demonstrating the need for comprehensive market development planning.

The camping market is not unique among outdoor recreation markets in its fragmentation of the forces that influence market expansion and development. The rate of market expansion is controlled largely by the hundreds of equipment manufacturers and their individual and collective mass persuasion tactics. And the rate of market development through building more and better campsites is controlled by scores of public agencies and thousands of private developers (Hunt 1969).

In an ideally operating market system, expansion of demand should stimulate expansion of supply after a reasonable time lag. However, fragmented recreation market systems are far from ideal. Public agency development plans are highly subject to broad policy considerations and budget restraints that are totally unrelated to market situations. Private development planning--and even most corporate development planning--is totally uncoordinated and increasingly secretive.

The one segment of the system that offers a reasonable opportunity to introduce comprehensive development planning is the public sector at the Federal level. The luxury of planning in a vacuum may have been appropriate to the make-work projects of the 1930's, when recreation was a pawn of other national policies; but it is hardly appropriate to today's outdoor recreation market situations. Public recreation agency planning for the development of new recreation areas and the expansion of existing facilities must be tied to a total understanding of recreation market systems, the capabilities of the private sector, and industry's plans for expansion.

In addition to its role as a direct provider of recreation opportunities, the public sector also acts as a catalyst and stimulant to private investment. Campgrounds can be built where they are needed through public-private cooperation, and much more efficiently than they can through the competitive expansion of facilities on remote public holdings or by acquiring more public land and reducing the tax base in areas where private enterprise could operate profitably.

Historically, the public sector's role has been to move into a recreation market during its infancy in an attempt to set standards, stimulate economies, and respond to an apparent need that private enterprise cannot yet fill. Unfortunately, the public sector has rarely found it easy to move out as the market matures and use its resources to provide leadership in new directions. In failing to move out, it runs the certain risk of losing its former leadership role, becoming noncompetitive, lowering standards, and even depressing local economies because of lower-than-average price structures and higher-than-average wage rates.

Our camper market studies tell us that camping participation is declining. But they do not tell us how much of that decline is due to: (1) the direct effect of an inadequate supply of campsites; (2) the indirect effect of camper dissatisfaction due to lack of quality, variety, and appropriate geographic distribution of facilities; (3) a normal social trend resulting from increased camper involvement in other activities that compete for his free time; and (4) an artifact of the data resulting from the fact that camping trips took more time in years past because of less mobile equipment, poorer highways, and a poorer geographic distribution of developed campgrounds.

## CONCLUSION

In summary, just as the market research role changes with each new growth stage of a recreation market, so too does the role of outdoor recreation planners, developers, managers, and promoters. Historically, the public sector's role has been to move into a recreation market during its infancy in an attempt to stimulate the rural economy and set standards. Unfortunately, the public sector has not found it so easy to move out as the market matures.

The mass of research evidence, along with our unbiased understanding of the workings of growth curves, indicates that the camping market is well into growth stage 3 and that its potential for future expansion is rapidly being dried up.

The potential camping market is like a mine in which the yield is of a lower grade ore each passing year. Eventually, it may be necessary to abandon the mine and rework some of the tailings of past years; to expand the market by improving conditions in ways that will reattract the camping market dropouts and stimulate more camping activity by people who have already tried camping.

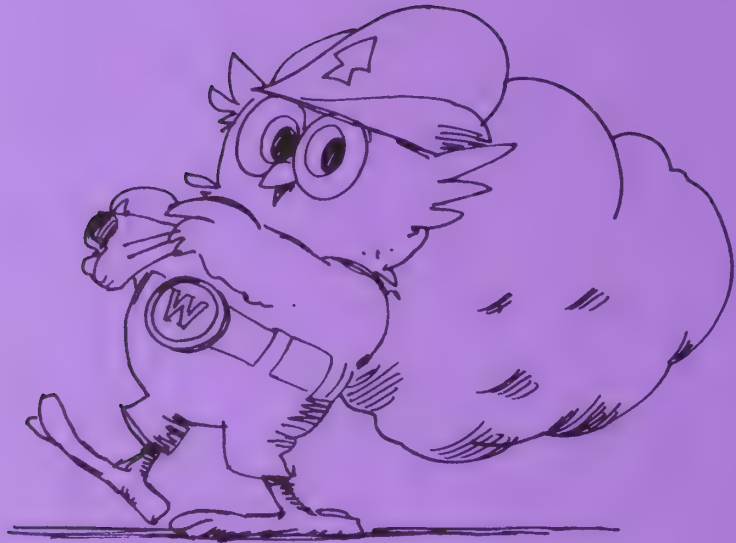
The maturing camping market is just one part of the even more complex and fragmented recreation industrial complex, which has become a major contributor to the economy. Based on the estimated size of that economic contribution and the proven value of market research in other less complex fields, our token investment in recreation market studies provides powerful proof that Grodzins' 1962 "Chaos of Confusion" doesn't begin to describe the situation in 1973!

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USDA FOREST SERVICE  
GENERAL TECHNICAL REPORT NC-10  
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# how craftsmen & home hobbyists can make and use wood plastic composite materials



Photographer: Elliott Mendelson

NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

| howard n. rosen

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# HOW CRAFTSMEN AND HOME HOBBYISTS CAN MAKE AND USE

## WOOD-PLASTIC COMPOSITE MATERIALS

Howard N. Rosen

### INTRODUCTION

How would you like to make soft maple or aspen harder, more colorful, more dimensionally stable, and easier to finish than the highest quality hardwoods? These benefits and many more are possible using WPC, which is an acronym recognized by professional woodworkers for wood-plastic composite materials. Its use also affords more versatility in the design of wood items ranging from tiepins to tabletops, produced in the home, school, or small shop.

WPC is formed when wood is filled with a plastic *monomer* and then heated in an oven. WPC combines the toughness, abrasiveness, and hardness of plastic with the intricate grain structure and strength of wood to make a most appealing amalgam. These plastic characteristics make WPC more durable and resistant to warping and swelling during changes in humidity than untreated wood. Moreover, the grain of the wood is accentuated in a satin-smooth surface of unfinished WPC. Addition of dyes can ensure even color throughout a WPC Product.

WPC is not without some disadvantages compared to wood. WPC is more costly than wood (\$1 to \$2/board foot higher) and it is more difficult to glue and to work. Furthermore, distortion can occur during polymerization; thus, greater care must be given to specifying dimensions when WPC is used.

### HOW WPC IS FORMED

Chemically, plastics are made by linking small molecules called monomers together to form long chains of molecules called *polymers*. The process, called *polymerization*, has been used to make WPC by two methods: (1) bombardment with gamma radiation or (2) heating of catalyzed monomer. Many different monomers that exist as a liquid at room temperature can be polymerized to form WPC.

Monomers, such as methyl methacrylate, vinyl acetate, and styrene, can be used to

form WPC. The most popular monomer used in WPC work is methyl methacrylate, known commercially in the polymerized form as Plexiglas or Lucite.<sup>1</sup> This monomer is recommended for small shop work with WPC material for the following reasons:

1. The low heat of polymerization reduces the chance of charring the wood.
2. The monomer is readily obtained through a number of companies.
3. The WPC material made with this monomer machines very well.
4. The monomer has a low toxicity.

Styrene monomer is a second choice to make WPC. It is not as desirable as methyl methacrylate because of odors that remain in the treated wood. A list of properties is given for methyl methacrylate and styrene below:

	Methyl methacrylate	Styrene
Boiling point (°F)	214	293
Density at 25° C (gm/cc)	0.94	0.90
Flash point-Tag open cup (°F)	55	94
Heat of polymeriza- tion (kCal/mole)	13.3	17.8
Viscosity at 25° C (cp)	.6	.7
Cost (dol/lb) <sup>2</sup>	.27	.16

<sup>1</sup>Use of trade names does not constitute endorsement of the products by the USDA Forest Service.

<sup>2</sup>Prices are based on 55-gal. drum and will increase for smaller quantities. Five-gal. quantities are available for \$16 or about \$0.40/lb.

Pure monomers can spontaneously polymerize during storage at room temperature. Spontaneous polymerization can be delayed by the addition of a chemical called an *inhibitor*. Typical inhibitors are hydroquinone (HQ), butyrate hydroxyl toluene (BHT), and monomethyl ether of hydroquinone (MEHQ). Retailers of monomers will give the purchaser a choice of inhibitor and inhibitor concentration. The decision concerning inhibitor amounts depends on how soon the monomer will be used. If the monomer will not be used over the course of a year, a higher amount of inhibitor should be used. For example, at 75°F, 10 parts per million (p/m) addition of MEHQ inhibitor will increase the life of methyl methacrylate monomer from 2 weeks to 2 years; 50 p/m of MEHQ will increase the life to 20 years. If possible, the higher concentrations should be avoided because the inhibitor decreases the effectiveness of the catalyst.

The basic process used to make WPC in the workshop is the catalyst-heat method. The monomer solution is forced into the voids of the wood structure and then *cured* (monomer becomes polymer) with heat. Because the formation of the plastic polymer causes considerable heat to be released (called the *heat of polymerization*), the heating of the monomer-soaked wood must be at a moderate temperature so the wood is not charred.

## EQUIPMENT NEEDED

Most of the equipment necessary to form the WPC can be found around the home or workshop. The following general equipment is needed to make WPC. An example is given for appropriate items that can be used:

*Weighing device*--kitchen scale.

*Impregnation tank*--3-in. diameter galvanized pipe with end caps.

*Surge tank*--1-gal solvent bottle with two-hole rubber stopper.

*Vacuum supply*--water aspirator (filter pump).

*Monomer supply tank*--1-gal bottle.

*Tubing*--thick-walled vacuum rubber tubing.

*Oven*--roof de-icing heating tape and steel pipe.

*Aluminum foil*

*Masking tape*

*Hose clamp*

The supplies can be obtained at a hardware store except for the water aspirator, which can be obtained from a chemical supply house for about \$3. A pressure and vacuum gauge used to monitor pressures during treatment is optional.

The impregnation tank can be any size or design providing it is capable of holding a vacuum and withstanding any pressure that might be applied to it. A galvanized steel nipple capped on both ends serves this purpose. The nipple is tapped so that a valve and/or pressure gauge can be attached.

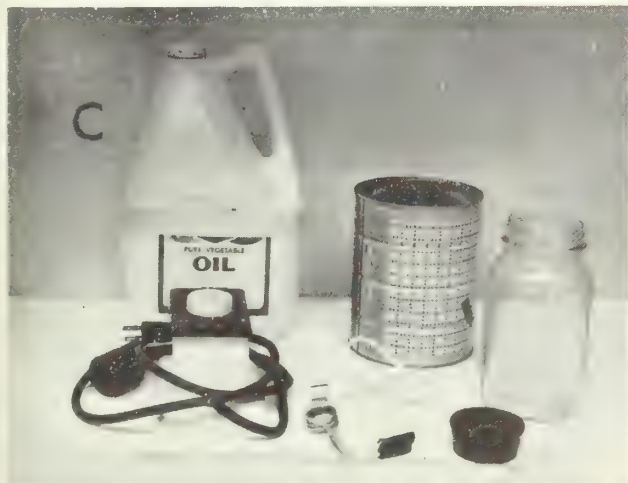
The surge tank should be capable of sustaining a vacuum without imploding. The tank can be wrapped with fine mesh window screen for added safety. A surge tank of at least five times the volume of the monomer solution is necessary to maintain a low vacuum once the monomer is introduced. Monomer solutions contain dissolved air, which is released when the monomer is introduced under vacuum.

Two safe and easily constructed ovens are shown in figure 1. The first oven consists of a 25-ft length of 125 watt roof de-icing heating tape wrapped around a 3 1/2 in galvanized pipe. The impregnated wood is placed in the pipe and loosely capped with a rubber stopper. A thermometer is inserted into the oven through a hole in the rubber stopper (figs. 1A and 1B). The second oven consists of a pickle jar placed in a coffee can filled with cooking oil. A small immersion heater is placed in the coffee can and a light dimmer switch is used to adjust current until 140 to 155° F is maintained. The pickle jar is loosely covered with a rubber stopper. Temperatures are measured using a thermometer extended through a hole in the rubber stopper into the jar. Treated wood is placed in the pickle jar for curing (figs. 1C and 1D). Exact temperature control is not required, but the closer the temperature is to 140 to 155° F the shorter the curing time. Temperatures in excess of 155° F will evaporate the monomer before it polymerizes.

## PREPARING THE WOOD

Wood used in making WPC should be dried to 6 to 12 percent moisture content. Green wood cannot be used because the wood voids are filled with water; thus, the monomer cannot enter the wood. For the best results in making WPC,

Figure 1.--(A) Parts for a pipe-oven;  
 (B) assembled pipe-oven;  
 (C) parts for an oil bath oven;  
 (D) assembled oil bath oven.



easily penetrated woods such as soft maple, birch, aspen, cottonwood, and basswood, should be used because they have an open and inter-connecting structure. Difficult-to-penetrate woods, such as red oak, white oak, and black walnut, can be used but the treatment is more difficult and the plastic is not as uniformly distributed throughout the wood.

The wood can be rough-shaped before treatment. In most cases, reshaping is necessary

after forming the WPC because of dimensional changes during the curing step.

#### PREPARING MONOMER SOLUTIONS

Weigh the components of the monomer solution on a kitchen scale (or gram balance) as shown in figure 2. Enough catalyzed monomer solution should be made to cover the wood pieces in the impregnation tank by several



Figure 2.--Weighing portions for monomer mixture.

inches and still leave an inch of monomer solution remaining in the monomer supply tank. Mix the monomer with 0.2 percent by weight catalyst. Either benzoyl peroxide or azobisisobutyronitrile (Vazo) can be used as the catalyst, although Vazo is preferred because it prolongs monomer storage life and gives greater color stability. The catalysts sell for about \$2/pound. If color is desired, add 1 percent by weight of dye to the solution. An optional crosslinking agent, ethylene glycol dimethacrylate (EGD), which costs about \$2 per pound, will make the wood easier to sand and machine.

### IMPREGNATING THE WOOD

Arrange the equipment as shown in figure 3. Attach the aspirator to a water outlet having a pressure of 20 lb/in.<sup>2</sup> or greater to achieve a vacuum of less than 1/3 in. of mercury.

Plug the surge tank with a two-hole stopper. Insert a tube of some rigid material, such as plastic, into the left hole. This tube must be long enough to extend to the bottom of the surge tank. Insert another tube of rigid material into the right hole; this tube should not protrude more than 1 in. into the surge tank. This ensures that any water backup from the aspirator fills the surge tank, not the impregnation tank.

Connect thick-walled tubing capable of supporting a vacuum from the aspirator to the rigid tube in the left hole of the

stopper and connect the rubber tubing from the impregnation tank to the rigid tube in the right hole. This tubing system must be free of leaks; otherwise a vacuum cannot be maintained.

The rubber tubing connecting the impregnation tank to the monomer supply tank can be attached to the valve on the impregnation tank either before or after a vacuum is drawn; however, this tubing should extend to the bottom of the monomer supply tank, as shown in figure 3.

Place wood pieces in the impregnation tank weighted with a heavy metal object so they will not float in the monomer solution. Open the upper valve (A) on the impregnation tank and close the lower valve (B). Turn the water on and let it run until the air is completely evacuated from the impregnation tank.

Then isolate the aspirator by attaching a hose clamp to the rubber tubing connecting the aspirator to the surge tank. If you have not already done so, connect the tubing from the monomer tank to the lower valve (B) on the impregnation tank and open valve B.

Add enough monomer so that the level of the solution in the impregnation tank is at least 2 in. above the wood pieces; otherwise, the plastic will be unevenly distributed in the wood. Soak the wood pieces under vacuum at least 5 min., while the entrapped air flows into the surge tank.

Then remove the hose clamp so that atmospheric pressure can force the monomer into the wood for at least 30 min. Remove the wood pieces from the monomer and let them drain.

To ensure impregnation in difficult-to-impregnate woods, such as red and white oak, isolate the impregnation tank from the surge tank and the monomer supply tank after the ordinary 30-min. soaking period. Using a compressor or pump, pressurize the impregnation tank to 50 lb/in.<sup>2</sup> and let the wood pieces soak an additional 2 hrs.

The unused catalyzed monomer solution should be placed in a refrigerator and stored at about 35° F. Once the catalyst has been added to the monomer, the life of the monomer is considerably shortened. At room temperature, polymerization can occur in a

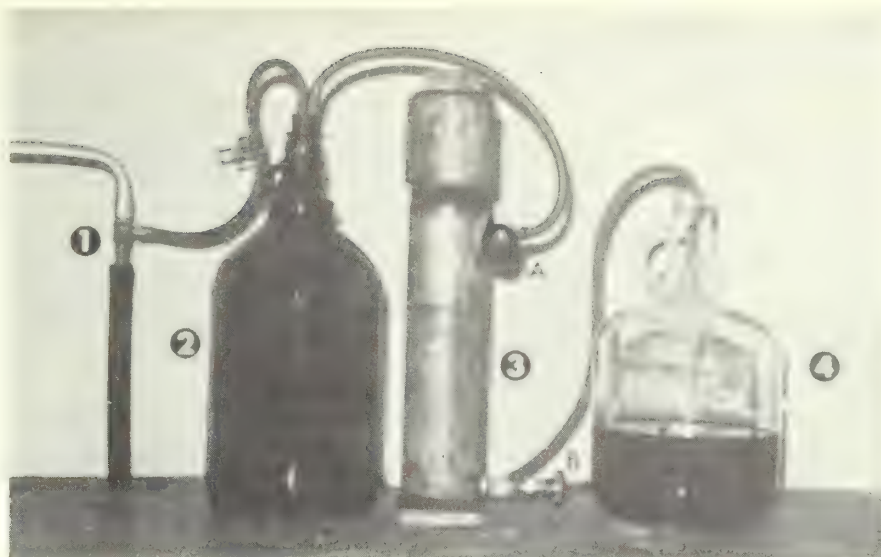


Figure 3.--Equipment arrangement for impregnation of monomer solution into the wood: (1) water aspirator, (2) surge tank, (3) impregnation tank, and (4) monomer supply tank.

few hours. After polymerization has occurred in the storage container, the contents cannot be removed without destroying the container.

### CURING OF THE IMPREGNATED WOOD

The first step in curing the treated wood is to wrap it tightly in aluminum foil. Seal the folds with masking tape to avoid evaporation of the monomer during curing. Cure the treated wood for 10 hrs at 140 to 155° F and then unwrap and air it in a well-ventilated area to remove residual monomer. The concentrated monomer vapors can explode or catch fire so ovens with open flame or open heating elements, such as kitchen ovens, should not be used.

### ADDING DYE TO MONOMER SOLUTIONS

The addition of dyes to the monomer solution gives the craftsman more versatility for creative projects. The dyes must be soluble in the monomer; thus, oil soluble dyes and not pigments are used. A colorant that

is merely suspended in the monomer, such as a pigment, will separate from the monomer during impregnation of the wood and will be filtered out by the wood structure. The dye concentration in the monomer for making WPC must be greater than normally used to color plastics because the wood will require more dye for coloration. Approximately 1 percent dye gives pleasing results.

Dyes tend to inhibit the polymerization of the monomer. This inhibition varies according to the dye used. In some cases, extra catalyst must be added to overcome the effects of the dye. Furthermore, some dyes are difficult to dissolve in monomers. The dye will more readily dissolve if it is premixed in a few drops of solvent such as acetone, methanol, or isopropyl alcohol (rubbing alcohol).

The final color of the WPC is difficult to determine without actually making the WPC material. If color is important, a test piece can be processed to determine the effects of the dye. The same dye can give varying results depending on wood type, dye concentration, monomer, catalyst, and finish. Most green

and black dyes turn blue after curing, so these colors are difficult to impart into the WPC by this process.

## GLUING

Polyvinyl, urea-formaldehyde, and casein glues are not recommended for bonding WPC pieces. Resorcinol and epoxy resin give good bonding strengths when used properly with WPC. The surfaces to be bonded should be scuff sanded, the glue double spread (one-half of the adhesive should be spread on each of the mating surfaces), and the pieces assembled by clamping them together. Curing is accomplished in an oven at 140° F for 3 hrs or overnight at room temperature.

Conventional wood glues can be used to bond sections of wood before making WPC. The processing of WPC in most cases does not affect previously bonded surfaces. Glue lines will not diminish the effectiveness of the penetration but will become more noticeable in the final product because the monomer solution cannot penetrate hardened glue.

## MACHINING

The WPC material can be machined on a lathe, bench saw, jointer, and drill press much the same as untreated wood. WPC material is harder and more dense than untreated wood so tool life is reduced. Carbide-tipped tools will last longer and make machining easier. The addition of a crosslinking chemical in the monomer mixture proves its usefulness in the machining and sanding of the WPC material. Without the crosslinker, the plastic in the WPC can soften and clog sawteeth, drill bits, and sandpaper. The crosslinking chemical raises the softening temperature of the plastic; thus, the material machines better. WPC will split when nailed. The material is fastened much like plastic material by being drilled and threaded for bolts or screws.

## FINISHING

WPC pieces can be buffed to a high luster finish unattainable with untreated wood. Linseed or vegetable oil or wax can be worked into the surface of the piece to darken colors. If the object is to be used to serve or store food, a vegetable oil is recommended. Varnishes can be applied to further enhance the surface quality.

## EFFECTIVENESS OF THE WPC TREATMENT

Calculations should be made before finishing the wood to check the effectiveness of the impregnation and the amount of polymerization achieved. First, determine your wood density by dividing wood weight by wood volume. Next, determine the *maximum* possible impregnation of methyl methacrylate or styrene for the density of your wood (fig. 4). Finally the *actual* percentage impregnation of monomer is determined by the following relationship:

$$\text{Percent impregnation} = \frac{(\text{weight of treated wood} - \text{weight of untreated wood}) \times 100}{\text{weight of untreated wood}}$$

For easily impregnated woods, such as soft maple, the ratio of the *actual* percentage to that of *maximum* possible percentage should be greater than 0.7. More-difficult-to-penetrate woods will yield lower ratios: e.g., a value of 0.3 is reasonable for red oak. Low values of impregnation can be caused by leaks in the treating system, failure to completely submerge the wood in the monomer solution, and the use of too small a surge tank.

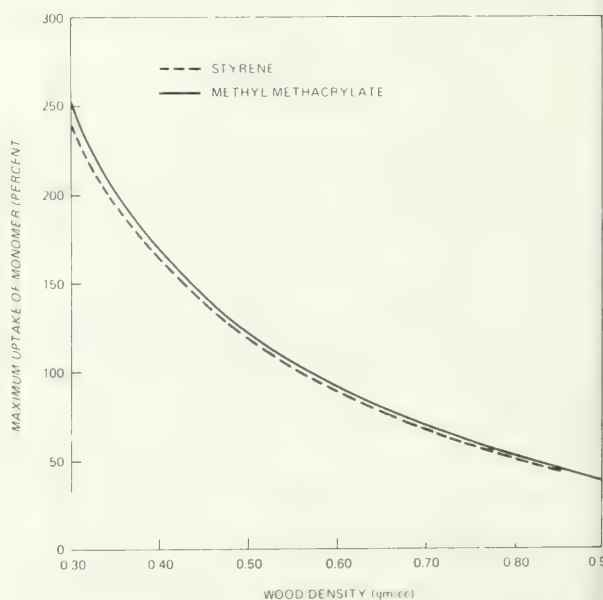


Figure 4.--Percent of maximum uptake of monomer for various wood densities.

The calculation to determine the amount of polymerization is:

$$\text{Percent polymerization} = \frac{(\text{weight of WPC after curing} - \text{weight of untreated wood}) \times 100}{(\text{weight of treated wood} - \text{weight of untreated wood})}$$

If the percentage polymerization is below 75 percent, there is a possibility of insufficient catalyst or too short a curing time.

## SAFETY

Extreme care must be taken to ensure that vapors are not exposed to an open flame, heating element, or spark. The flash point (which indicates the flammability of substances) for methyl methacrylate (see p.1) shows it is capable of burning and exploding at room temperature in high concentrations. The monomer, crosslinking agent, and catalyst should be stored in a cool, dark place and refrigerated if possible.

Work should be done in well-ventilated areas. Because monomers are heavier than air and collect in a layer near the floor, exhaust fans should be operating near the floor. Monomer vapors have characteristic odors and eye or throat irritation can be interpreted as a warning that the concentration in the area is too high. Safety precautions obtained from the company from which the monomers are purchased should be carefully followed.

The production of surfaces that come in contact with foodstuffs should be compatible with health regulations. Only dyes resistant to foodstuffs should be used in these cases. Vegetable oil is an acceptable oil to enhance the color tone on surfaces that come in contact with food.

## EXAMPLE PROJECTS

### Salt and Pepper Shaker

An apple salt shaker and pear pepper shaker can be made from 1-inch-thick soft maple (fig. 5). Glue wood sections with urea-formaldehyde resin to make a piece 3 in. square by 1 ft in length. Shape the outline of the pear and apple on a lathe. Mix two monomer solutions using the following ingredients: 500 gm of methyl methacrylate monomer and 1 gm of benzoyl peroxide. Add 5 gm of

a foodstuff-resistant dye to the first solution and 5 gm of another foodstuff-resistant dye to the second solution. Treat the apple and pear in solutions of their appropriate colors. After curing at 155° F overnight and air drying for 1 day, turn the final dimensions and sand the surfaces on a lathe. Drill a 3/4-inch hole in the bottom of the pear and apple to 3/8 inch from the top to form the cavity for the salt and pepper. Then drill 1/16-in. holes in the tip of the shakers in the form of an S for salt and P for pepper. Use a bottle cork to plug the holes in the bottom of the shakers. Finally, rub linseed oil into the exterior surface of the pieces to bring out the colors.



Figure 5.--Apple salt shaker and pear pepper shaker.

### Candy Dish

A two-toned candy dish, about 5 1/2 in. in diameter and 6 in. high can be made from sticks of soft maple. Rough cut 16 sticks, 3 by 6 by 3/4 in. Mix two monomer solutions using the following ingredients: 5 lb of methyl methacrylate monomer, 1/6 oz of Vazo, and 3 oz of EGD crosslinker. Add 1 oz of dye to the first solution and 1 oz of another dye to the second. Treat half the sticks with the first monomer solution and half the sticks with the other monomer solution. After curing, use resorcinol to glue pairs of the same color sticks lengthwise to make eight 6-in. square plates. Clamp for 15 hr so the glue can set. Rough cut the 6-in. square section into disks ranging from 4 to 6 in. in diameter depending on the contour of the dish. Using resorcinol glue the disks in an alternating color pattern and again clamp for 15 hr to set the glue; seven pieces for the dish and two pieces for the top (the small

piece on top can be made using the excess from rough cutting the disks). Shape the two sections on a lathe into the dish and top. Buff and finish using a vegetable oil to produce a beautiful two-toned candy dish (fig. 6).



Figure 6.--Two-toned candy dish.

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#### LIST OF SUPPLIERS

##### Catalyst

E. I. DuPont de Nemours & Co. (Vazo)  
Industrial Chemicals Dept.  
Wilmington, DE 19898

Lucidol Division (Benzoyl peroxide)  
Pennwalt Corp.  
1740 Military Rd.  
Buffalo, NY 14240

##### Crosslinker

Sartomer Co. (EGD)  
Bolmar and Niels St.  
Westchester, PA 19380

##### Dye<sup>3</sup>

Allied Chemical Corp. (Salvinac Red 3BS; Ios Orange)  
P. O. Box 6  
Solvay, NY 13209

American Cyanamid (Calco Oil Red ZMQ)  
Pigments Division  
Boundbrook, NJ 08805

American Analine Prod., Inc. (Amaplast Red C)  
25 McLean Blvd.  
Paterson, NJ 07509

<sup>3</sup>Any oil soluble dyes can be used; shown in parenthesis are some of the dyes used at our Laboratory in Carbondale.

CIBA-Geigy Corp. (Irgacet Red 2BL; Irgacet  
Brown 2GL)  
Pigments Dept.  
Ardsley, NY 10502

E. I. DuPont Nemours & Co. (Oil Blue A; Latyl  
Orange NST)  
Organic Chemicals Dept.  
Dyes and Chemicals Division  
Wilmington, DE 19898

Pylam Products Co.  
95-10 218th St.  
Queens Village, NY 11429

Sandoz Colors and Chemicals (Acetosol Blue  
GLS; Acetol Yellow RLS)  
Route No. 10  
East Hanover, NJ 07936

#### Glue

Ashland Chemical Co.  
P. O. Box 2219  
Columbus, OH 43016

Bordon Chemical  
50 W. Broad St.  
Columbus, OH 43215

Pacific Resins and Chemicals, Inc.  
3434 13th Ave. SW  
Seattle, WA 98134

#### Monomers

*Methyl methacrylate*

E. I. DuPont de Nemours & Co.  
Plastics Dept.  
Wilmington, DE 19898

Rohm and Haas  
Industrial Chemicals Dept.  
Independence Mall W.  
Philadelphia, PA 19105

*Styrene*

Monsanto Polymers & Petrochemicals Co.  
800 N. Lindbergh Blvd.  
St. Louis, MO 63166

*Water aspirator*

A. H. Thomas Co.  
P. O. Box 779  
Philadelphia, PA 19105

Sargent-Welch Scientific Co.  
7300 N. Linder Ave.  
Skokie, IL 60076







*Sing along with Woodsy and help stop pollution.*



# the effects of declining population growth on the demand for housing

1975-1990



1990-2020



thomas c. marcin

NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

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# THE EFFECTS OF DECLINING POPULATION GROWTH ON THE DEMAND FOR HOUSING

Thomas C. Marcin

The Nation is now on a path toward eventual zero-population growth which will profoundly affect the demand for housing in the coming decades. In 1973 the Nation's birth and fertility rates reached all-time lows. The fertility rate--i.e., the number of births per woman upon completion of child-bearing years--is now below the long-run replacement rate of 2.1 births per woman needed to eventually stabilize the Nation's population, assuming no immigration. Furthermore, the trend to lower fertility rates shows no signs of tapering off. Nevertheless, the Nation's population will continue to grow well into the next century because of the present age structure (fig. 1); and, of course, the fertility rate could rise in the future. In addition, the age composition of the population will change dramatically in the next several decades, greatly affecting housing demand in the future.

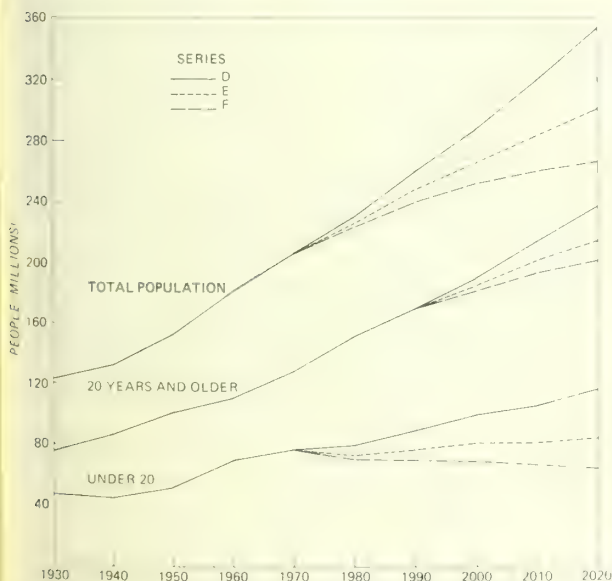


Figure 1.--Total U.S. population, population 20 years and older and population under 20 for 1930, 1940, 1950, 1960, and 1970 with projections to 2020.

## METHOD OF PROJECTION

The projections presented are based upon a computer model of housing demand by type of unit and region under specific assumptions relating to population growth and social and economic change (Marcin 1972).

The model is based partly on the life-cycle model of housing demand relating household formation to population change by age group (Campbell 1966, Smith 1966). One purpose of the household life-cycle model is to isolate changes in demographic factors from changes caused by other factors. Age will be the only demographic factor considered. Other factors, such as sex, race, and marital status, could also be considered. Age is, however, most important because it serves as a good indicator for many related variables. For example, sex ratio, marital status, income, and assets all have age-related cycles. Age also affects other aspects of housing demand, especially the demand for certain types of units and second homes. Shifts in the age composition of the population can lead to changes in housing demand even if economic conditions and consumer preferences remain unchanged.

Annual projection of population by age class forms the starting point for a model. Next, household formations and type of unit occupied are related to the population age groups. Household formations are then distributed to the regions on the basis of adult population.

In addition to household formations, there are two other important sources of housing demand: the demand for units to (1) maintain the inventory of vacant units and provide second homes, and (2) replace those removed from the existing housing stock by natural disaster, demolition, abandonment, merger, or other similar causes (Maisel 1963).

This paper examines the effects of declining population growth and the changing age-mix of the population on the long-run demand for housing by type of unit. A summary of several alternative projections of possible housing demand is presented for the period 1975 to 2020 based upon alternative assumptions of population growth.

These are not intended as projections of actual housing production but rather as a measure of possible housing demand under certain conventional assumptions: continued economic growth, moderate inflation, and the occurrence of no catastrophic event such as a major war, etc. Lack of credit, runaway costs, shortages of materials, or a major recession could reduce housing production. In the long run, however, the Government would probably institute housing programs to alleviate any major housing shortage.

The second part of the model provides a method for projecting vacancy and replacement demand by region. Regional vacancy and replacement rates are input into the model, and total housing demand by type of unit is projected for each region. An index based on household formation and type of housing occupied by age class is used to estimate the housing-type mix. National totals are obtained by summing the regions.

## THE CHANGING STRUCTURE OF THE POPULATION

In the last several years net household formation has been at an all-time high while population growth has declined to its lowest rate since the 1930's. This paradox is possible because of the extremely unbalanced age distribution in the U.S. population. Today, population increase is largely concentrated in the age group born in the "baby boom" of the 1940's and 1950's.

Three major trends in births have shaped the age structure of our population (fig. 2). First, birth declined from about 3 million to 2.3 million in the decade 1925-35. A large increase followed as births rose from 2.5 million in 1939 to 4.3 million in 1957. The last decade has seen the sharpest drop in births in history, to 3.14 million in 1973.

The most recent projections of population for the period 1972 to 2020 are based on four fertility rate assumptions:



Figure 2.--Number of births in the U.S., 1909-1972, with projections to 2000.

2.8, 2.45, 2.1, and 1.8 births per woman (U.S. Bureau of the Census 1972a). These are lower than previous assumptions because of the sharp decline in the fertility rate since 1970 and the continued decline in births expected by young wives during the last 5 years (U.S. Bureau of the Census 1972b). The current fertility rate is about 1.9, the lowest in American demographic history.

One set of age-sex specific mortality rates and net immigration rates is used for all four series. Annual immigration is assumed to be 400,000.

All projections used an average age of childbearing of 25.8 years. However, this average age could increase as women delay childbearing and work before starting a family. Part of the present decline in fertility may be attributed to a postponement of childbearing. At the present time, an average of two children per women would appear to be the most likely assumption. However, the current pessimistic outlook of the public, caused in part by the present social and economic upheaval, combined with the general availability of sophisticated birth control methods, legalized abortion, and the public campaign against population growth could keep the fertility rate below the long-run replacement rate. People may choose to maintain a high standard of living by not having children.

The importance of the changing age composition of the population for age-related activities such as housing cannot be overemphasized. The impact of past fluctuations in births is reflected in population changes by age class. In the

past 20 years the decline in births of the 1930's, followed by the large increase in births from 1940 to 1960, followed in turn by a sharp decline in births over the past 10 years, created an age-class bulge in our population. The future passage of this population bulge through the various age classes will clearly influence housing demand.

From 1950 to 1970 most of the increase in population was in the age group under 30 years (fig. 3). From 1970 to 1990 the increase will be concentrated in the group aged 25 to 45. In the 1980's and 1990's the needs of middle-aged people are likely to dominate our society, replacing the youth-orientated markets of the 1960's. During this period the number of people under 25 is expected to decline substantially.

## RELATION OF HOUSING DEMAND TO THE POPULATION AGE STRUCTURE

Household formation and the demand for certain types of housing units and second homes vary with the age of individuals. These differences in housing demand have remained fairly stable over long periods in the U.S. due in part to regular patterns of income, income expectation, assets, family status, and preferences over the life cycle (Campbell 1966).

Individuals generally form a separate household sometime in their 20's and by age 30 about 50 percent head a separate household, most of which are married couples. Headship—i.e., the ratio of household heads to total population—then

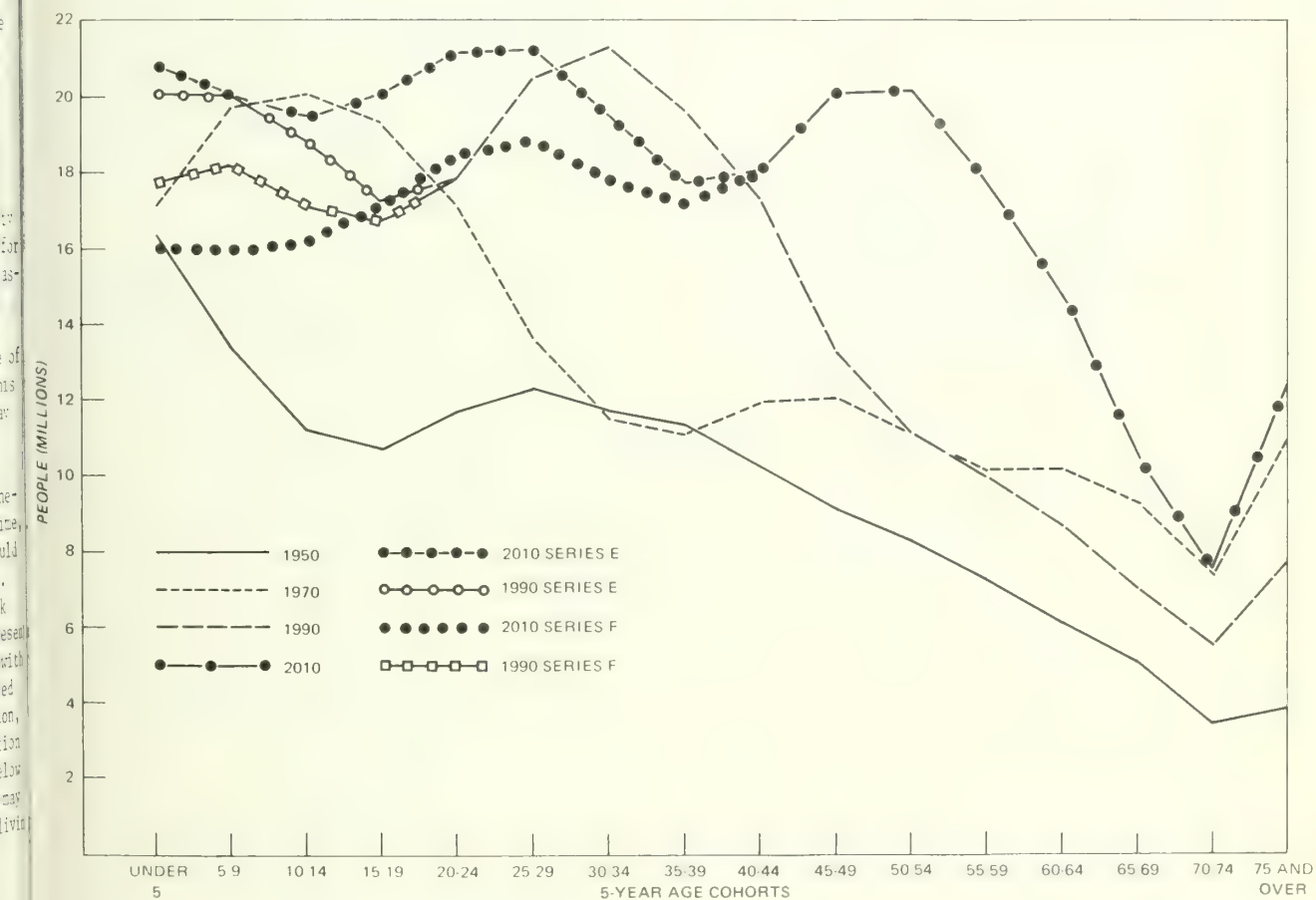


Figure 3.--U.S. population by 5-year age cohorts for 1950 and 1970 with projections for 1990 and 2010.

risers gradually until about two-thirds of all surviving individuals in their 70's head a separate household. A major determinant of headship is the level and distribution of personal income. Since 1950 there has been a steady increase in headship, particularly among the young and old age groups (fig. 4). This reflects the trend toward nuclei family units with younger and older generation members splitting off to form separate households. Present social and economic trends seem to indicate that the increase in single-person households will continue, aided by liberalized divorce laws, equal opportunity for women, the emerging role of the single life as an alternative life style, and continued Government programs to subsidize housing for the poor and elderly. However, at some point in the future, headship rates will level off. A major disruption of economic growth or a change in life styles to larger household units could even cause headship rates to decline.

Two series of headship rates are used to account for the current high rate of household formation. An upper series projects headship increasing at the present trends until 1980, and more moderate increases thereafter (fig. 4). The lower projection series assumes a more moderate increase in headship. As income continues to grow, headship will depend more on life styles and preferences and could be above or below the projections used in this study.

The available data indicate that the demand for different types of housing varies with age and income of the household head (Atkinson 1966; Smith 1966; U.S. Bureau of the Census 1973a, 1973b, 1973c; U.S. Department of Housing and Urban Development 1968).

Typically the young householder first occupies an apartment or mobile home, then at about age 30 buys a moderately priced single-family home or townhouse. Later, as his financial position improves in middle age, he will upgrade his home. Finally, he will move to a smaller retirement home, apartment, or mobile home. In the last several years condominium apartments have added a new dimension to this progression and some people may decide to buy an apartment rather than a single-family home. It is difficult to tell how significant the condominium boom will be in the long run. However, the overwhelming preference of most middle-aged householders still appears to be for single-family homes (Lansing 1966, Lansing *et al.* 1964). Second-home ownership rates are also strongly related to age, most owners being 40 to 64 years (U.S. Bureau of the Census 1969).

There was little change in the type of housing unit occupied by the middle-aged group between 1960 and 1970: nearly 80 percent of household heads age 35 to 54 occu-

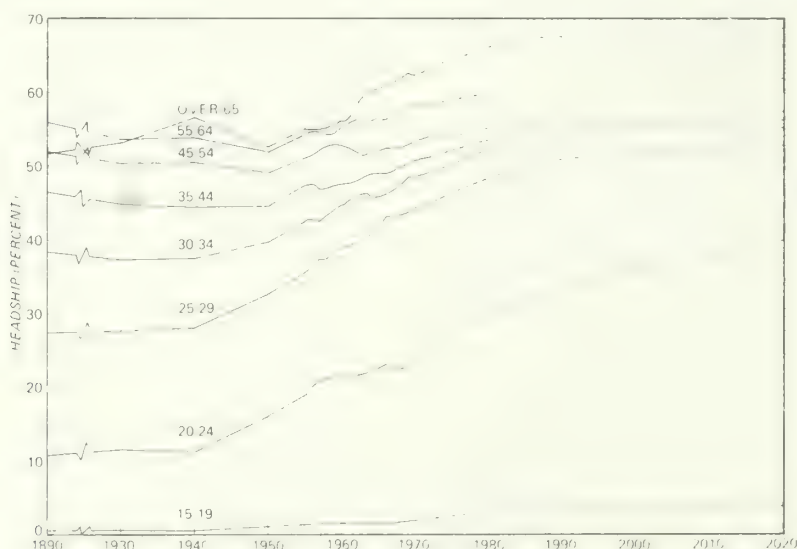


Figure 4.--Headship rates by age class for 1890, 1930, 1940, 1950, and 1955-1972, with projections to 2020 (high series).

pied one-unit structures (fig. 5). There was an increase in multi-unit occupancy by younger household heads and for householders 65 and older, primarily a shift in the rental market to new apartments from the surplus of single-family homes built up in the 1950's. Mobile home occupancy increased for all age groups, especially young household heads. This trend is expected to continue (table 1). A moderate shift to multi-unit occupancy is also projected, coupled with a corresponding lower rate for one-unit demand.

#### FUTURE HOUSEHOLD FORMATION

Net household formation, i.e., the net increase in the total number of households, has risen sharply in recent years, from about 1 million a year in the 1950's and 1960's to over 1.6 million a year in the early 1970's. Although special factors, such as the end of the Viet Nam war and

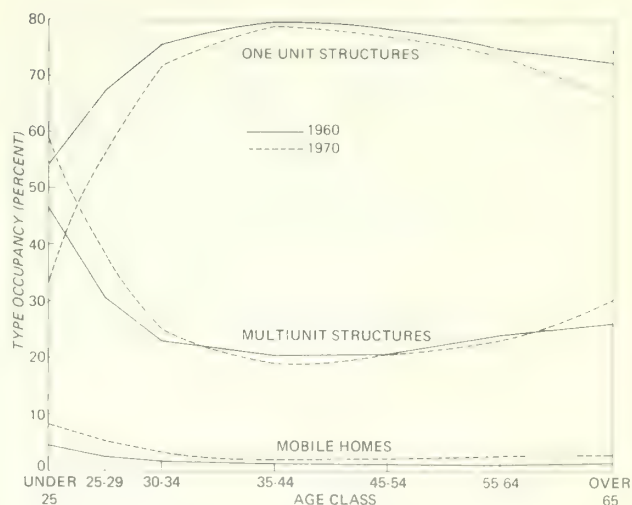


Figure 5.--Housing type occupancy rates in the U.S. by age class for 1960 and 1970.

Table 1.--Housing occupancy rates in the United States by type of structure and age of occupants for 1960 and 1970 with projected incremental occupancy rates to 2020.

(In percent)

#### OVERALL OCCUPANCY RATE

Year	Housing type	Age of occupants (years)							
		15-19	20-24	25-29	30-34	35-44	45-54	55-64	65+
1960	One-unit structures <sup>1/</sup>	47	55	68	75	79	78	75	73
	Multi-unit structures	47	41	30	23	20	21	24	26
	Mobile units	6	4	2	2	1	1	1	1
	Total	100	100	100	100	100	100	100	100
1970	One-unit structures		<sup>2/</sup> 33	57	72	79	77	74	67
	Multi-unit structures		59	38	25	19	21	23	30
	Mobile units		8	5	3	2	2	3	3
	Total		100	100	100	100	100	100	100
INCREMENTAL OCCUPANCY RATE									
1970-2020	One-unit structures	5	5	30	50	65	63	55	49
	Multi-unit structures	65	65	45	32	22	24	28	33
	Mobile units	30	30	25	18	13	13	17	18
	Total	100	100	100	100	100	100	100	100

1/ These rates are for all one-unit structures and differ from those previously published by the author that classified attached one-unit structures with multi-unit structures.

2/ This estimate is for all households under 25 years. Source:

1960--Author's estimates based on unpublished data from the one-in-a-thousand sample of population characteristics from the 1960 census which is available on magnetic tapes. U.S. Bureau of the Census, U.S. Census of Housing: 1960. Public Use Sample.

1970--Author's estimates based on data from the 1970 Census of Housing. U.S. Bureau of the Census, Census of Housing: 1970. Final Report HC(7)-6, Mobile Homes, Table A-1, and Final Report HC(7)-1, Housing Characteristics by Household Composition, Table A-5.

the draft, may have increased the rate of household formation in this period, continued sharp increases in the number of persons in their 20's and early 30's will keep net household formation high until the mid-1980's. In this study, the total number of households is projected to increase by 14.9 to 16.4 million in the 1970's and by 13.0 to 13.8 million in the 1980's.

In the 1990's alternative assumptions about future population growth become important. Household formation will likely decline in this decade to less than a million a year due to the recent decline in births (table 2). After the turn of the century, about 1 million households will be formed annually unless there is an upswing in fertility rate.

Table 2.--Projections of housing demand in the United States by components, annual averages, 1975-1980, and 10-year periods to 2020

(Thousand units)

HIGH PROJECTIONS

Period	Household formations	Conventional vacancies	Replacement units	Other mobile units <sup>1/</sup>	Conventional Mobile units <sup>1/</sup>
Series E					
1975-1980	1,682	197	671	220	138
1981-1990	1,374	230	781	310	130
1991-2000	980	264	896	362	123
2001-2010	1,139	246	997	426	164
2011-2020	1,059	192	1,101	490	169
Series F					
1975-1980	1,682	197	671	220	139
1981-1990	1,372	230	781	310	130
1991-2000	883	252	894	357	116
2001-2010	870	209	981	401	144
2011-2020	723	144	1,059	445	148
Series D					
1975-1980	1,682	197	671	220	139
1981-1990	1,379	231	781	310	130
1991-2000	1,172	288	899	371	139
2001-2010	1,538	301	1,025	467	194
2011-2020	1,500	255	1,165	559	205
LOW PROJECTIONS					
Series E					
1975-1980	1,468	176	607	213	126
1981-1990	1,302	221	701	296	122
1991-2000	917	253	799	340	114
2001-2010	1,075	235	887	400	154
2011-2020	985	180	977	458	156
Series F					
1975-1980	1,468	176	607	213	126
1981-1990	1,300	220	701	295	122
1991-2000	826	241	797	336	107
2001-2010	820	200	874	376	135
2011-2020	655	134	940	416	138
Series D					
1975-1980	1,468	176	607	213	126
1981-1990	1,306	221	701	296	122
1991-2000	1,096	275	802	349	130
2001-2010	1,458	288	912	438	182
2011-2020	1,402	240	1,033	524	191

<sup>1/</sup> Includes mobile units used for purposes other than a primary residence such as second homes, because vacant units are not counted in the housing inventory by the Bureau of the Census.

Changes in the age-mix of household heads are occurring that greatly influence the type of unit demanded. The effects of the changing age structure of the population are reflected in long-run fluctuations of the number of household heads by age class. To illustrate the potential effects on housing demand of the changing age-mix, consider two key age groups for housing

demand: (1) those households headed by persons under 30 who are most likely to demand apartments and mobile homes, and (2) the 35- to 44-year-old age group who typically occupy single-family homes. From 1966 to 1975 household heads under 30 are expected to increase by 5.7 million while only a slight decrease is projected for the 35- to 44-year-old age group (fig. 6). This

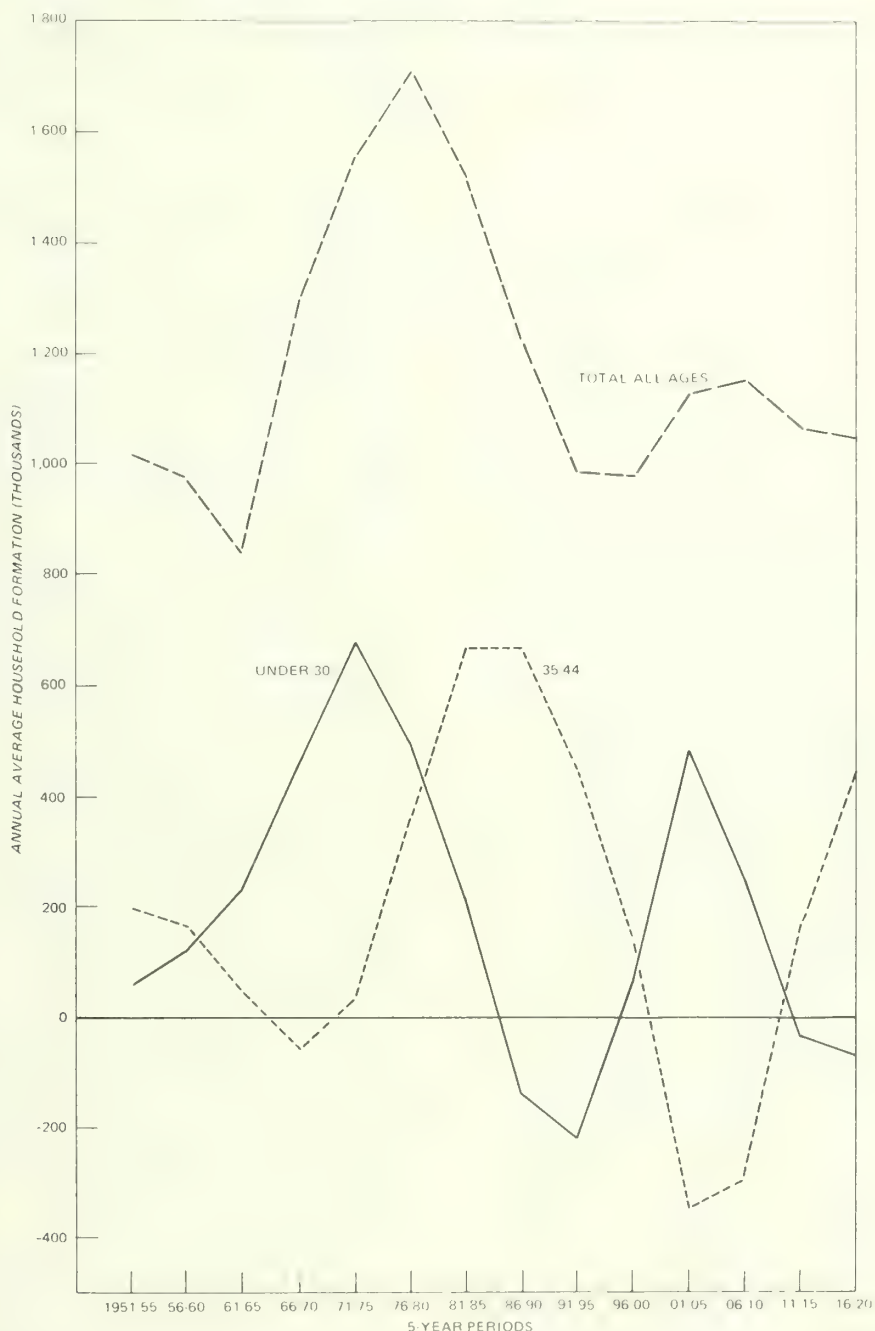


Figure 6.--Average household formation by selected age groups for 5-year periods 1951-1970 with projections to 2020 (Series E high projections).

in part explains why apartment and mobile home demand has boomed in this period and single-family home demand has languished. Similar fluctuation will occur in the number of household heads in other age groups through time. In the 1970's the number of middle-aged household heads will increase rapidly while the number of households headed by persons under 30 will begin to decrease in the latter half of the decade. In the 1980's an upsurge of single-family housing demand is likely to occur due to changing the population age structure.

### PROJECTION OF VACANCY AND REPLACEMENT DEMAND

The second phase of the projection model requires estimates of the other components of housing demand: vacancy and replacement demand. In this section we will add estimates of future vacancy and replacement rates to the projections of household formations to obtain projections of total housing demand by type of unit.

Vacancies may occur for many reasons and may be categorized into: (1) those units available for sale and rent, and (2) those units held vacant for other reasons such as second homes and hence not available in the housing market. Little increase in the vacancy rate is projected for the next 10 years because of the expected housing demand. In the late 1980's and 1990's, vacancies are projected to increase more rapidly as housing demand shifts to meet the needs of the middle-aged householder. Total vacancies are projected to increase from 9.1 percent in 1980 to 12.1 percent in 2020. Mobile homes that are vacant or used as second homes are not included in the vacancy-rate statistics.

Replacement demand is the other major component of housing demand. Net replacement demand in this study is divided between conventional housing units and mobile homes. Two assumptions are made about net replacement rates: (1) replacement rate for conventional housing units was assumed to be about the same as the 1960's, ranging from 0.78 to 0.85 percent, and (2) replacement rate for mobile homes was assumed to be 4 to 5 percent. Overall the replacement rate varied from about 1 to 1.1 percent of the total housing stock. Mobile homes that become vacant or are used as second homes are no longer counted

in the housing inventory. These projections of replacement rates may be somewhat optimistic in view of the present shortages of energy, materials, and capital.

### SUMMARY OF HOUSING DEMAND

Total housing demand is projected to remain high until the late 1980's (fig. 7). By 1990, however, a decline in housing demand is projected to occur because of the "baby bust" of the last 10 years. An upper and lower series of projection of possible housing demand were made for each population Series D, E, and F.

Total housing demand, including mobile homes, is projected to be between 2.6 and 2.9 million units annually for 1975 to 1980 (table 3).<sup>1/</sup> This is about the level of production for the housing boom of 1971 to 1973, and substantially above the 1.7 million units produced in the 1960's. Net household formations are projected to remain high, averaging between 1.5 and 1.7 million annually. Vacancies are projected to increase by nearly 200,000 units a year, while replacement demand is projected to vary from 820,000 to 890,000 units annually (table 2).

In the 1970's the demand for multi-unit structures and mobile homes is expected to remain strong because of large increases in net household formation for people under 30 years of age. By the mid-1970's the demand for single-family housing units is expected to begin to rise rapidly as the many people born in 1940 to 1960 approach middle age. For the period 1975 to 1980 one-unit structures are projected to constitute 57 percent of total conventional housing demand of about 2 to 2.2 million units annually. Mobile home demand is projected to average between 630,000 and 690,000 units or about 24 percent of total housing demand.

In the 1980's total housing demand is projected to be between 2.6 to 2.8 million units. Demand will remain high in the first half of the decade and then decline in the second half because of declining household formations. The demand by components for

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<sup>1/</sup> These projections are of basic long-run trends in housing demand under the assumption made in the study and do not account for short-run fluctuations in housing productions that could vary as much as 20 percent.

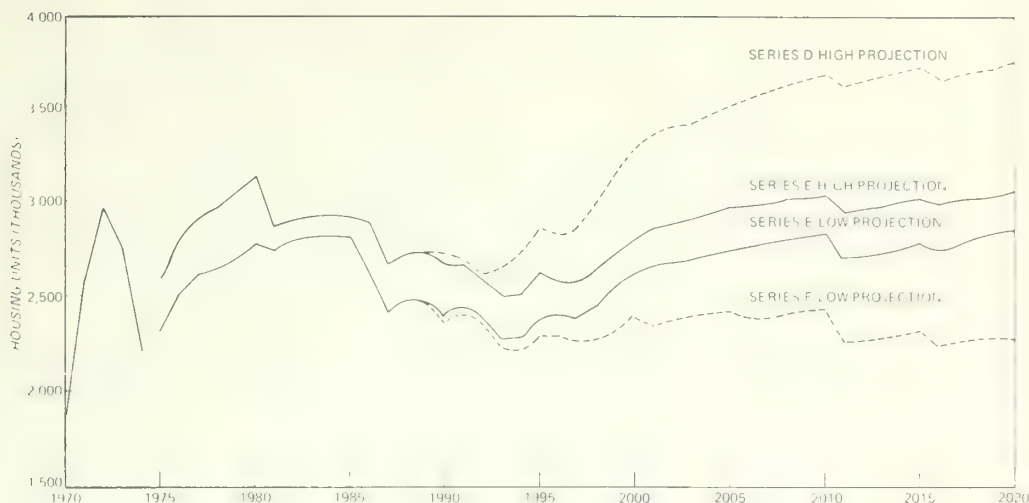


Figure 7.--Estimates of housing production, 1970-1974, with projections of total housing demand to 2020.

The decade includes 1.3 to 1.4 million new households annually, 220,000 to 230,000 additional vacant units a year, and 1.0 to 1.1 million units for replacements, of which 100,000 are mobile home replacements. In addition, it is estimated that about 130,000 additional mobile homes will be required that are not used as primary residences or counted in the housing stock, as defined by the Census Bureau. These units may be vacant, used as second homes, or for other purposes. Twenty percent of total mobile home shipments are assumed to be in this category.

The demand for one-unit structures is expected to continue to rise in the 1980's because most of the growth in households for the decade will be concentrated in the early middle-aged group. On the other hand, the demand for multi-unit structures is expected to decline substantially by the mid-1980's because of the decline in numbers of young households. Mobile home demand is also projected to decline for the same demographic reasons. By the late 1980's one-unit structures could account for 70 percent of new construction.

Throughout the 1980's, new construction is projected to remain at about 2 to 2.2 million units a year; about two-thirds of the demand will be for one-unit structures. Mobile home demand is projected to be between 400,000 to 650,000 units a year.

In the 1990's, alternative population growth rate assumptions become important for the first time. A large decline in house-

hold formation will occur in the decade. If the birth rate of the last year continues, household formation could drop to an annual rate of 830,000 to 980,000 or nearly half the peak rate of the 1970's. For the decade, projected total housing demand varies from 2.3 to 2.9 million depending on population assumptions. Replacement demand is projected to vary from 11 to 13 million units. Vacant units are projected to increase by 2.4 to 2.9 million units, reflecting a probable upswing in second home demand.

For the first time replacement will become the most important component of housing demand. If replacement demand, which can be postponed, falls short of the projections, a further decline in housing demand would occur.

In the early 1990's, one-unit housing demand is projected to reach a peak as the number of householders aged 35 to 54 increases rapidly, while there is a decrease in the number of household heads under 30. But by the late 1990's, an upswing in multi-unit demand is expected. For the entire decade, one-unit structures could account for nearly 70 percent of conventional housing demand.

After the turn of the century the population growth rate assumption becomes increasingly important. For the two decades after 2000, total housing demand could vary from only 2.3 to 2.5 million units annually for the low fertility rate assumptions (1.8 births per woman) or demand could jump to 3.4 to 3.7 million units a year if fertility

Table 3.--Projections of housing demand in the United States by type of unit, annual averages, 1975-1980, and 10-year periods to 2020

(Thousand units)

HIGH PROJECTIONS

Period	:	Total	:	New construction						
	:	all types	:	All	:	One-unit	:	Multi-unit	:	Mobile
	:		:	starts	:	:	:	:	:	
Series E										
1975-1980		2,908		2,219		1,272		947		689
1981-1990		2,825		2,176		1,448		728		649
1991-2000		2,624		2,007		1,362		645		617
2001-2010		2,972		2,150		1,248		902		822
2011-2020		3,010		2,165		1,359		806		845
Series F										
1975-1980		2,908		2,219		1,272		947		689
1981-1990		2,822		2,174		1,448		726		648
1991-2000		2,501		1,923		1,354		569		578
2001-2010		2,606		1,886		1,132		754		720
2011-2020		2,520		1,778		1,070		708		742
Series D										
1975-1980		2,908		2,219		1,272		947		689
1981-1990		2,831		2,180		1,448		732		651
1991-2000		2,870		2,174		1,384		791		696
2001-2010		3,526		2,554		1,454		1,100		972
2011-2020		3,684		2,659		1,646		1,013		1,025
LOW PROJECTIONS										
Series E										
1975-1980		2,590		1,958		1,120		838		632
1981-1990		2,642		2,030		1,370		660		612
1991-2000		2,423		1,849		1,275		574		574
2001-2010		2,751		1,980		1,162		818		771
2011-2020		2,758		1,970		1,251		719		778
Series F										
1975-1980		2,590		1,958		1,120		838		632
1981-1990		2,638		2,028		1,370		658		610
1991-2000		2,309		1,771		1,268		503		538
2001-2010		2,405		1,731		1,051		680		674
2011-2020		2,283		1,594		970		624		689
Series D										
1975-1980		2,590		1,958		1,120		838		632
1981-1990		2,646		2,033		1,370		663		613
1991-2000		2,652		2,004		1,295		709		648
2001-2010		3,278		2,366		1,363		1,003		912
2011-2020		3,390		2,434		1,527		907		956

rate should suddenly increase to 2.45 births per woman.

Regardless of the population series assumed, replacement demand will increase because of the growth in the size of the housing stock and the greater proportion of mobile homes. For example, for the 2.1 fertility rate, replacement demand is pro-

jected to range from 13 and 14 million units for the decade 2001-2010 and from 14 to 15 million units for 2011-2020. In the long run, housing demand will become more dependent on replacement of the existing housing and increases in second home demand. The future level of these components of housing demand is much less certain than the level of future household formation.

Ultimately, the mix of new construction will average about 60 percent one-unit structures and 40 percent multi-unit structures, according to the assumptions made about housing type occupancy. By the year 2020 mobile homes are expected to average about 30 percent of housing demand. Much of this demand is for replacement of the growing stock of older mobile homes.

## CONCLUSIONS

The large numbers of people born in the 1950's who are now entering the housing market, and current expectations about future economic growth, indicate that the recent high-level housing demand will continue until the late 1980's, despite periodic disruptions of housing production because of short-term credit cycles. But, by 1990 a large decrease in housing demand could occur because of the decline in births of the last 10 years. The level of net household formations in the early 1990's may fall about half from the present rate of 1.6 million. Increases in replacement and vacancy demand are projected to moderate the effect on total housing demand. In fact, replacement will become the most important component of housing demand. Attainment of the projected replacement rate in the 1990's is by no means certain. By the 1990's, much of the housing stock will be relatively new and the replacement rates could fall below the projected levels. If this should happen, a major recession in housing could occur in the 1990's.

After the year 2000, projections of total housing depend increasingly on alternative assumptions about the future population growth rate. Long-run housing demand could average as low as 2.5 million housing units a year if the present level of fertility continues.

If the fertility rates stabilize at the replacement level, total housing demand is projected to average 2.75 to 3 million units annually for 2001 to 2020. A drop in fertility rates to 1.8 would result in a projected demand of 2.3 to 2.6 million units, while an increase in fertility to 2.45 children per woman increases housing demand projections to 3.3 to 3.6 million units a year.

Types of housing units demanded are likely to change dramatically over the next 30 years if historic relations of type of housing unit occupied to age of household head continue. These changes will be caused

by unprecedented changes in the age distribution of the population.

A large demand for multifamily units and mobile homes will continue into the early 1980's because of continued large increases in households under age 30. However, overcapacity in apartments may occur by the late 1980's as the number of households under 25 greatly declines.

By the late 1970's and 1980's a great increase in demand for one-unit structures should occur as the number of households in the 30- to 44-year-old age group increases rapidly. This demand will at first be greatest for some type of moderately priced housing unit. Later, the demand for more expensive homes should build up as the households begin to upgrade their housing units. In the 1990's a new era of individually styled and custom-built homes may develop as an affluent, middle-aged society seeks to improve the quality of its housing.

Second home demand in the 1970's may not be as great as is often expected due to lack of increase in population in the key 40- to 60-year-old age group. By 1990, however, a large potential demand for second homes should develop as the number of householders in their 40's grows rapidly.

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pencils    etc etc }



# TREES of the NORTH CENTRAL STATES

their  
distribution  
and use

Helen J. Lewey

NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE



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# TREES OF THE NORTH CENTRAL STATES: THEIR DISTRIBUTION AND USES

Helen J. Lewey

## FOREWORD

During my 14 years as a Statistical Assistant at the Carbondale field office of the North Central Forest Experiment Station, I have developed considerable interest in the uses of the different trees and shrubs on which I have compiled technical data. Because of the increasing number of people interested in the properties of our forest trees I have compiled a list of the major species found in our Station territory (Illinois, Indiana, Iowa, Minnesota, Michigan, Missouri, and Wisconsin). Although the focus of this report is on trees in these States, some of the species also may be found in adjoining areas.

Throughout history man has found wood indispensable for shelter, for fire to cook food and warm himself, and for weapons. Through years of technological study and research, man has found diverse and sophisticated uses for wood and bark. Transparent films, filaments, fabrics, plastics, and chemicals are a few of the less conventional forms of wood consumption. New industries, such as pulp and paper mills, are being built to meet an increasing demand for paper products.

The ease with which hardwood and softwood species can be worked into a variety of shapes and securely fastened together with simple tools and fasteners make them readily adaptable to many uses. The more important uses are listed in this report prepared as a ready reference for individuals, schools, the wood-using industry, and research organizations. Because there are often many common names for a species, it was generally necessary to select one reference and use it as a guide for the best common name (Little 1953). However, in some instances widely used common names are listed with a reference to the name used by Little.

Ailanthus:

*Ailanthus altissima* (Mill.) Swingle

Distribution: Illinois and Indiana.

Uses: Ornamental. Originally from China. Wood has the appearance of ash.

Uses: Tool handles, baseball bats, tennis rackets, furniture, interior trim, boatbuilding, slack and tight cooperage, boxes, crates, agricultural implements, and dairy, poultry, and apiary supplies.

Apple:

Sweet crab

*Malus coronaria* (L.) Mill.

Distribution: Illinois, Indiana, Michigan, Missouri, and Wisconsin.

Uses: Fruit used for jelly.

Aspen:

Bigtooth

*Populus grandidentata* Michx.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Pulp, excelsior, matches, corestock, clothespins, cabin construction, boxes, crates, furniture, general construction lumber, and dairy, poultry, and apiary supplies.

Hedge (see osage-orange)

Ash:

Biltmore (see white ash)

Quaking

*Populus tremuloides* Michx.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Same as bigtooth aspen.

Black

*Fraxinus nigra* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Cabinetwork, interior trim, and basketmaking.

Baldcypress

*Taxodium distichum* (L.) Rich.

Distribution: Illinois, Indiana, and Missouri.

Uses: Exterior trim of buildings, greenhouses, planking, boat- and shipbuilding, shingles, posts, poles, crossties, sash, doors, tanks, vats, coffins, silos, boxes, crates, railroad ties, slack cooperage, and tubs.

Blue

*Fraxinus quadrangulata* Michx.

Distribution: Illinois, Indiana, Iowa, Michigan, Missouri, and Wisconsin.

Uses: Moderately important; similar to white ash.

Green

*Fraxinus pennsylvanica* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Similar to white ash.

Basswood:

American

*Tilia americana* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Veneer, plywood, corestock, baskets, slack cooperage, excelsior, boxes, crates, sash trunks, valises, coffins, tubs, kitchen cabinets, handles, shade and map rollers, venetian blind slats, and dairy, poultry, and apiary supplies.

Pumpkin

*Fraxinus profunda* (Bush) Bush

Distribution: Illinois, Indiana, and Missouri.

Uses: Unimportant.

Red (see pumpkin ash or green ash)

White

*Fraxinus americana* L.

Distribution: Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin.

## White

*Tilia heterophylla* Vent.

Distribution: Illinois, Indiana, and Missouri.

Uses: Same as American basswood.

Blue (see American hornbeam)

## Beech:

### American

*Fagus grandifolia* Ehrh.

Distribution: Illinois, Indiana, Michigan, Missouri, and Wisconsin.

Uses: Railroad ties, pulp, slack cooperage, flooring, furniture, boxes, crates, fuel, tool handles, ironing boards, clothespins, veneer, and fuel.

## Birch:

### Paper

*Betula papyrifera* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Pulp, lumber, turned articles, veneer, boxes, baskets, furniture, crates, interior trim, butcher blocks, railroad ties, musical and scientific instruments, slack cooperage, tooth picks, and medical tongue depressors.

### River

*Betula nigra* L.

Distribution: Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin.

Uses: Same as paper birch.

### Yellow

*Betula alleghaniensis* Britton

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Furniture, flooring, veneer, railroad ties, slack cooperage, musical instruments, and novelties.

Boxelder (see maple)

## Buckeye:

### Ohio

*Aesculus glabra* Willd.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri

Uses: Boxes, crates, cigar boxes, artificial limbs, woodenware, trunks, valises, plywood, drawing boards, furniture, and plaques for pyrography.

### Yellow

*Aesculus octandra* Marsh.

Distribution: Illinois and Indiana.

Uses: Same as Ohio buckeye.

## Buffaloberry:

### Silver

*Shepherdia argentea* (Pursh) Nutt.

Distribution: Iowa, Minnesota, and Wisconsin.

Uses: Ornamental.

## Bumelia:

### Gum

*Bumelia lanuginosa* (Michx.) Pers.

Distribution: Illinois and Missouri.

Uses: Unimportant. Produces clear, viscid gum.

## Butternut:

*Juglans cinerea* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Edible kernel. Substitute for black walnut. Furniture, interior trim, cabinetwork, woodenware, boxes, and crates.

## Buttonbush:

### Common

*Cephalanthus occidentalis* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Contains tannin.

Buttonwood (see sycamore)

## Catalpa:

### Northern

*Catalpa speciosa* Warder

Distribution: Illinois, Indiana, and Missouri.

Uses: Fenceposts, rails, interior trim, cabinetwork, lumber, and fuel.

### Cherry:

Black

*Prunus serotina* Ehrh.

Distribution: Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin.

Uses: Furniture, printers' blocks, patterns, professional and scientific instruments, piano actions, interior trim, tool handles, woodenware, gunstocks, veneer, and paneling.

Pin

*Prunus pennsylvanica* L. f.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Unimportant. Fruit used for jelly.

### Chestnut:

American

*Castanea dentata* (Marsh.) Borkh.

Distribution: Illinois, Indiana, and Michigan.

Uses: Tannin, pulp, poles, fenceposts, railroad ties, slack cooperage, furniture, caskets, boxes and crates, millwork, and plywood. (Most of the chestnut were killed by the blight, *Endothia parasitica*, but the dead trees are still useful.)

### Chokecherry:

Common

*Prunus virginiana* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Fruit used for jelly.

### Coffeetree:

Kentucky

*Gymnocladus dioica* (L.) K. Koch

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Ornamental. Fenceposts, crossties, rough construction, furniture, cabinetwork, interior trim, and fuel.

### Cottonwood:

Eastern

*Populus deltoides* Bartr.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Pulp, excelsior, veneer, plywood, lumber, furniture, poultry coops, ironing boards, musical instruments, boxes, crates, tubs, and pails for food products.

Swamp

*Populus heterophylla* L.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Same as eastern cottonwood.

### Cucumbertree:

*Magnolia acuminata* L.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Furniture, venetian blinds, siding, interior trim, sash, doors, boxes, and crates.

### Devils-walkingstick:

*Aralia spinosa* L.

Distribution: Illinois, Indiana, and Missouri.

Uses: Ornamental.

### Dogwood:

Flowering

*Cornus florida* L.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Ornamental. Shuttles, spools, mallet heads, golfclub heads, bobbin heads, small pulleys, jewelers' blocks, turnpins, and machinery bearings.

### Elm:

American

*Ulmus americana* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Slack cooperage, boats, basket veneer, boxes, crates, furniture (chair rockers and arms), interior trim, tool handles, saddle trees, and dairy, poultry, and apriary supplies.

## Rock

*Ulmus thomasi* Sarg.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Same as American elm.

## September

*Ulmus serotina* Sarg.

Distribution: Illinois and Missouri.

Uses: Unimportant.

## Slippery

*Ulmus rubra* Mühl.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Same as American elm.

## Winged

*Ulmus alata* Michx.

Distribution: Illinois, Indiana, Missouri.

Uses: Same as American elm.

## ir:

### Balsam

*Abies balsamea* (L.) Mill.

Distribution: Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Pulp, boxes, crates, sash, slack cooperage, general construction lumber, and woodenware.

## ackberry:

*Celtis occidentalis* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Furniture, boxes, and crates.

## hthorn:

### Cockspur

*Crataegus crus-galli* L.

Distribution: Illinois and Missouri.

Uses: Ornamental.

## Downy

*Crataegus mollis* Schelle

Distribution: Illinois, Michigan, and Missouri.

Uses: Mallets and tool handles.

## Green

*Crataegus viridis* L.

Distribution: Illinois, Indiana, and Missouri.

Uses: Edible fruit; used for making jelly.

## Hemlock:

### Eastern

*Tsuga canadensis* (L.) Carr.

Distribution: Indiana, Michigan, Minnesota, and Wisconsin.

Uses: Pulpwood, general construction lumber, boxes, crates, sash, doors, cabinets, and trunks.

## Hickory:

### Bitternut

*Carya cordiformis* (Wangenh.) K. Koch

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Nut is extremely bitter. Furniture, panelings, dowel pins, tool handles, ladders, skis, gymnastic bars, and fuel for smoking meats.

### Mockernut

*Carya tomentosa* Nutt.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Edible nut. Fuel for smoking meats.

### Pecan

*Carya illinoensis* (Wangenh.) K. Koch

Distribution: Illinois, Indiana, Iowa, and Missouri.

Uses: Edible nut. Furniture, paneling, and flooring.

### Pignut

*Carya glabra* (Mill.) Sweet

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Tool handles and furniture.

### Shagbark

*Carya ovata* (Mill.) K. Koch

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Edible nut. Furniture, tool handles, and ladders.

### Shellbark

*Carya laciniosa* (Michx. f.) Loud.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Same as shagbark hickory.

Water

*Carya aquatica* (Michx. f.) Nutt.

Distribution: Illinois and Missouri.

Uses: Bitter nut. Same as bitternut hickory.

Holly:

American

*Ilex opaca* Ait.

Distribution: Illinois, Indiana, and Missouri.

Uses: Turnings, novelties, furniture, rulers, tool handles, engravings, scroll work, and carvings. Occasionally stained black to imitate ebony for piano keys.

Honeylocust:

*Gleditsia triacanthos* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Missouri, and Wisconsin.

Uses: Fenceposts, crossties, veneer, furniture, and interior trim.

Hoptree:

Common

*Ptelea trifoliata* L.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Roots used as a tonic.

Hophornbeam:

Eastern

*Ostrya virginiana* (Mill.) K. Koch

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Furniture, fenceposts, tool handles, mallets, and fuel.

Hornbeam:

American

*Carpinus caroliniana* Walt.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Tool handles, levers, woodcogs, mallets, wedges, and fuel.

Locust:

Black

*Robinia pseudoacacia* L.

Distribution: Illinois, Indiana, and Missouri.

Uses: Fenceposts, poles, railroad ties, insulator pins, lumber, boxes, and crates.

Maple:

Black

*Acer nigrum* Michx. f.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Veneer, furniture, musical instruments, interior trim, bowling pins, flooring, tool handles, boxes, crates, butcher blocks, railroad ties, sash, doors, wood-  
enware, and standard wood in U. S. shear-test blocks.

Boxelder

*Acer negundo* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Furniture and woodenware.

Mountain

*Acer spicatum* Lam.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Ornamental.

Red

*Acer rubrum* L.

Distribution: Illinois, Indiana, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Ornamental.

Silver

*Acer saccharinum* L.

Distribution: Illinois, Indiana, Iowa, Minnesota, Michigan, Missouri, and Wisconsin.

Uses: Ornamental. Pulpwood; substituted for sugar maple.

Striped

*Acer pennsylvanicum* L.

Distribution: Illinois, Indiana, Michigan, and Minnesota.

Uses: Ornamental.

Sugar

*Acer saccharum* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Flooring, musical instruments, bowling pins, boxes, crates, veneer, interior trim, and syrup

Mountain-ash:

American

*Sorbus americana* Marsh.

Distribution: Illinois, Indiana, Michigan, and Wisconsin.

Uses: Ornamental.

Mountain-laurel:

*Kalmia latifolia* L.

Distribution: Indiana.

Uses: Small tree, ornamental.

Ruberry:

Red

*Morus rubra* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Edible fruit. Fenceposts, furniture, caskets, agricultural implements, and slack cooperage.

Sannyberry:

*Viburnum lentago* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Ornamental.

Oaks, red:

Black

*Quercus velutina* Lam.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Blackjack

*Quercus marilandica* Muenchh.

Distribution: Illinois, Indiana, and Iowa.

Cherrybark

*Quercus falcata* var. *pagodaefolia* Ell.

Distribution: Illinois, Indiana, and Missouri.

Northern pin

*Quercus ellipsoidalis* E. J. Hill

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Northern red

*Quercus rubra* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Nuttall

*Quercus nuttallii* Palmer

Distribution: Missouri.

Pin

*Quercus palustris* Muenchh.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Scarlet

*Quercus coccinea* Muenchh.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Shingle

*Quercus imbricaria* Michx.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Shumard

*Quercus shumardii* Buckl.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Southern red

*Quercus falcata* Michx.

Distribution: Illinois, Indiana, and Missouri.

Willow

*Quercus phellos* L.

Distribution: Illinois and Missouri.

Uses for the red oaks: Railroad ties, railroad cars, wooden parts in motor and nonmotor vehicles, slack cooperage, fenceposts, mine timbers, poles, piling, veneer, furniture, interior paneling, flooring, agricultural implements, ship- and boatbuilding, caskets, boxes, crates, and firewood. Southern red oak bark is rich in tannin.

Oaks, white:

Bur

*Quercus macrocarpa* Michx.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Chestnut

*Quercus prinus* L.

Distribution: Illinois, Indiana, and Michigan.

Chinkapin

*Quercus muehlenbergii* Engelm.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Overcup

*Quercus lyrata* Walt.

Distribution: Illinois, Indiana, and Missouri.

Post

*Quercus stellata* Wangenh.

Distribution: Illinois, Indiana, Iowa, and Missouri.

Swamp chestnut

*Quercus michauxii* Nutt.

Distribution: Illinois, Indiana, and Missouri.

Swamp white

*Quercus bicolor* Willd.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

White

*Quercus alba* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses for the white oaks: Same as red oaks plus tight cooperage.

Osage-orange:

*Maclura pomifera* (Raf.) Schneid.

Distribution: Illinois, Michigan, and Missouri.

Uses: Archery bows, fenceposts, lumber, fuel, and insulator pins. Yellow dye is extracted from roots.

Pawpaw:

*Asimina triloba* (L.) Dunal

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Ornamental. Edible fruit.

Pecan (see hickory)

Persimmon:

Common

*Diospyros virginiana* L.

Distribution: Illinois, Indiana, Iowa, and Missouri.

Uses: Edible fruit. Golfclub heads, billiard cues, shuttles, spools, bobbins, boxes, crates, and tool handles.

Pine:

Eastern white

*Pinus strobus* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Interior trim, patternmaking, matches, signs, pulpwood, caskets, boxes, construction lumber, venetian blinds, and dairy and poultry supplies.

Jack

*Pinus banksiana* Lamb.

Distribution: Michigan, Minnesota, and Wisconsin.

Uses: Pulpwood, railroad ties, posts, mine timbers, boxes, crates, and fuel.

Loblolly

*Pinus taeda* L.

Distribution: Introduced by plantations in Illinois, Indiana, and Missouri.

Uses: Same as shortleaf pine.

Red

*Pinus resinosa* Ait.

Distribution: Illinois, Michigan, Minnesota, and Wisconsin.

Uses: Pulp, railroad ties, poles, posts, construction lumber, boxes, crates, venetian blinds, and interior and exterior trim.

Shortleaf

*Pinus echinata* Mill.

Distribution: Illinois and Missouri.

Uses: Lumber, flooring, boxes, railroad ties, car siding, poles, posts, pulpwood, excelsior, structural timber, boatbuilding, tanks, silos, woodenware, novelties, and basket veneer.

Virginia

*Pinus virginiana* Mill.

Distribution: Indiana.

Uses: Pulpwood, fuel, and posts.

Plum:

American

*Prunus americana* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Little commercial use; varies widely in its palatability.

Serviceberry:

Downy

*Amelanchier arborea* (Michx. f.) Fern

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Ornamental. Edible berry. Tool handles.

Poplar (see yellow-poplar)

Poplar:

Balsam

*Populus balsamifera* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Pulpwood, excelsior, furniture (concealed parts), poultry coops, ironing boards, and tubs for food products.

Lombardy

*Populus nigra* var. *italica* Muenchh.

Distribution: Illinois.

Uses: Ornamental. Form of the European black poplar.

Silverbell:

Carolina

*Halesia carolina* L.

Distribution: Illinois and Indiana.

Uses: Ornamental.

Smoketree:

American

*Cotinus obovatus* Raf.

Distribution: Missouri.

Uses: Ornamental.

Redbud:

Eastern

*Cercis canadensis* L.

Distribution: Illinois, Indiana, Iowa, Michigan, and Missouri.

Uses: Ornamental.

Soapberry:

Western

*Sapindus drummondii* Hook. & Arn.

Distribution: Missouri.

Uses: Unimportant.

Redcedar:

Eastern

*Juniperus virginiana* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Cedar chests, closets, interior woodwork, lead pencils, posts, poles, rustic furniture, and novelties.

Sourwood:

*Oxydendrum arboreum* (L.) DC.

Distribution: Illinois and Indiana.

Uses: Tool handles, bearings for machinery, and sled runners.

Sparkleberry:

Tree

*Vaccinium arboreum* Marsh.

Distribution: Illinois, Indiana, and Missouri.

Uses: Edible berry.

Sassafras:

*Sassafras albidum* (Nutt.) Nees

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Lumber (often sold for black ash), oil (used for flavoring tea and candies), fenceposts, rails, wooden pails, and small boats.

Spruce:

Black

*Picea mariana* (Mill.) B. S. P.

Distribution: Michigan, Minnesota, and Wisconsin.

Uses: Paddles, oars, pulpwood, slack cooperage, interior trim, musical instruments, boatbuilding, furniture, and ladder rails.

White

*Picea glauca* (Moench) Voss

Distribution: Michigan, Minnesota, and Wisconsin.

Uses: Boxes, crates, sounding boards, construction lumber, pulpwood, slack cooperage, interior trim, musical instruments, boatbuilding, furniture, ladder rails, paddles, and oars.

Sugarberry:

*Celtis laevigata* Willd.

Distribution: Illinois, Indiana, and Missouri.

Uses: Furniture, interior trim, boxes, and crates.

Sumac:

Staghorn

*Rhus typhina* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, and Wisconsin.

Uses: Ornamental.

Swamp-privet:

*Forestiera acuminata* (Michx.) Poir.

Distribution: Illinois, Indiana, and Missouri.

Uses: Unimportant.

Sweetgum:

*Liquidambar styraciflua* L.

Distribution: Illinois, Indiana, and Missouri.

Uses: Veneer, lumber, furniture, containers, railroad ties, pulpwood, mine props, boxes, and crates. Storax gum used in drugs and soaps obtained from the bark.

Sycamore:

American

*Platanus occidentalis* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Missouri, and Wisconsin.

Uses: Slack cooperage, boxes, crates, veneer, cigar boxes, furniture, cabinets, ties, ironing boards, butcher blocks, and fuel.

Tamarack:

*Larix laricina* (DuRoi) K. Koch

Distribution: Illinois, Indiana, Michigan, Minnesota, and Wisconsin.

Uses: Poles, railroad ties, rough lumber, pulpwood, boxes, crates, pails, and buckets.

Tree of heaven (see Ailanthus)

Tupelo:

Water

*Nyssa aquatica* L.

Distribution: Illinois and Missouri.

Uses: Veneer, plywood, pulp, furniture, tool handles, platform planking, floors, railroad ties, kitchen cabinets, boxes, crates, ironing boards, clothespins, and dairy, poultry, and apiary supplies.

Black (blackgum)

*Nyssa sylvatica* Marsh.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Same as water tupelo.

Walnut:

Black

*Juglans nigra* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Edible nut. Furniture, interior trim, cabinet work, veneer, paneling, gunstocks, caskets, woodenware, and novelties.

White (see butternut)

Waterlocust:

*Gleditsia aquatica* Marsh.

Distribution: Illinois and Indiana.

Uses: Fenceposts and crossties.

White-cedar:

Northern

*Thuja occidentalis* L.

Distribution: Illinois, Indiana, Michigan, Minnesota, and Wisconsin.

Uses: Poles, posts, cabins, pails, tubs, railroad ties, rustic furniture, shingles, boatbuilding, and woodenware.

**Willow:**

**Black**

*Salix nigra* Marsh.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Artificial limbs, veneer, pulpwood, charcoal, boxes, crates, furniture, and slack cooperage.

**Peachleaf**

*Salix amygdaloides* Anderss.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Charcoal and woodenware.

**Weeping**

*Salix babylonica* L.

Distribution: Illinois and Missouri.

Uses: Ornamental.

**Hitch-hazel:**

*Hamamelis virginiana* L.

Distribution: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.

Uses: Ornamental.

**Yellow-poplar:**

*Liriodendron tulipifera* L.

Distribution: Illinois, Indiana, Michigan, and Missouri.

Uses: Cigar boxes, patterns, coffins, plywood, furniture, interior trim, construction lumber, veneer, pulpwood, crates, musical instruments, fruit and berry boxes, toys, and novelties.

**Yellowwood:**

*Cladrastis lutea* (Michx. f.) K. Koch

Distribution: Illinois, Indiana, and Missouri.

Uses: Ornamental. Veneer, gunstocks, fuel, and yellow dye.

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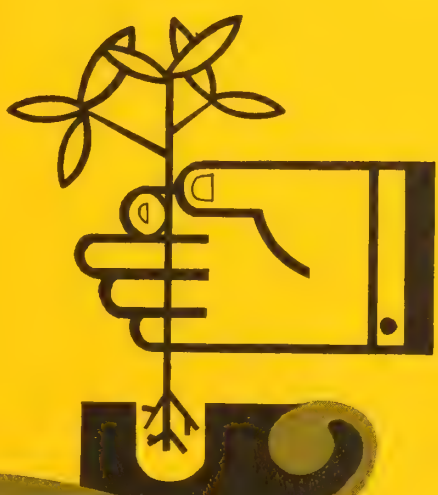






*Soil is for plants...not for tire tracks.*

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liography  
of

# Walnut

Supplement No.2

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## FOREWORD

Since publication of "An Annotated Bibliography of Walnut and Related Species," USDA Forest Service Research Paper NC-9, by David T. Funk in 1966, and "Annotated Bibliography of Walnut--Supplement No. 1," USDA Forest Service Research Paper NC-70, by Martha K. Dillow and Norman L. Hawker in 1971, we have accumulated an additional 223 literature references dealing with Juglans ecology, silviculture, and timber products. This supplement is an attempt to update the previous bibliographies by including citations that were unintentionally omitted in the original publications and those published since 1971.

The bibliography is arranged in alphabetical order by author. An index provides a list of items by subject matter. More than four-fifths of the items are annotated. Most of the remainder were either not seen by the author or were in a foreign language, with no English summary or translation available.

We would appreciate being notified of any errors in the list and also would be glad to know of any publications that were omitted and should be included in a future supplement.

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<sup>1</sup>Numbers appearing in bold-face type refer to publications containing information on *J. nigra*; numbers appearing in italics

refer to publications that do not contain any information on *J. nigra*.

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*In an effort to obtain information useful in establishing walnut plantations, patterns of growth and phenological characters of trees originating in different geographic locations have been observed. No geographic area produced unusually large or small seed. Trees from the southern sources generally flushed earlier, dropped their leaves later, grew taller, and had more lateral buds on the current year's terminal than trees from northern sources.*
23. Bey, Calvin F. 1973. CORRECTIVE PRUNING YOUNG BLACK WALNUT TREES--A NEW TWIST. North. Nut Grow. Assoc. Annu. Rep. 63(1972): 26-28, illus.  
*A "new twist" procedure for eliminating forks and multiple tops in young black walnut trees involves using weaker shoots as supports for straightening the most promising terminal. Judicious bending, taping, and clipping on young trees can increase the chances of producing high-quality boles.*
24. Bey, Calvin F. 1973. GENETIC VARIATION AND SELECTION. In *Black walnut as a crop*. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 62-65, illus. North Cent. For. Exp. Stn., St. Paul, Minn.  
*Research dealing with genetic variation and selection in black walnut has confirmed the idea of wide genetic diversity. Growth, form, leaf flush, leaf fall, and period of growth are genetically variable. Leaf flush usually begins 1 day earlier for every 85 mi south of the planting site that seed is collected. In field tests, leaf fall is delayed about 1 day for every 25 mi to the south that seed is collected. Trees from as far as 200 mi south of the planting site generally grow as large or larger in height and diameter than trees from local or northern sources.*
25. Bey, Calvin F. 1973. GROWTH OF BLACK WALNUT TREES IN EIGHT MIDWESTERN STATES--A PROVENANCE TEST. USDA For. Serv. Res. Pap. NC-91, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.  
*At age 6, survival of black walnut trees was not related to latitude of the source at six out of eight locations. Trees from as far as 200 mi south of the planting site generally grew as large or larger than trees from local or northern sources.*
26. Bey, Calvin F., Norman L. Hawker, and Paul L. Roth. 1972. VARIATIONS IN GROWTH AND FORM IN YOUNG PLANTATION BLACK WALNUT TREES. South. For. Tree Improv. Conf. Proc. 11: 120-127, illus.  
*Growth, form, and phenological characters were evaluated in young black walnut trees. Analysis of variance revealed that most characters showed source differences while only a few characters showed family within-source differences. Heritability estimates*

indicate that the potential for genetic gain for growth, flushing, and leaf fall characters are good.

27. Bey, Calvin F., A. S. Mickelson, and M. Gerardo. 1972. BLACK WALNUT SEEDLING SEED ORCHARD DEVELOPMENT--A CASE HISTORY. Northeast. Area Nurserymen's Conf. Proc., p. 48-56, illus.

*The major phases essential for developing a black walnut seedling seed orchard include: (1) defining the planting and seed collection areas, (2) collecting seed for the seed orchard trees, (3) selecting the orchard site, (4) establishing the orchard, (5) caring and maintaining the orchard, (6) selecting superior phenotypes and thinning the orchard, and (7) planning for the next-generation orchard.*

28. Blyth, James E. 1973. TIMBER DEMAND AND USE. *In* Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 7-9. North. Cent. For. Exp. Stn., St. Paul, Minn.

*The use of walnut increased from 1933 to the mid-1960's, then probably peaked-out between 1963 and 1968. The proportion of walnut logs used for veneer has been increasing during the last 2 decades while the proportion used for lumber has been declining. Most export logs are cut into veneer. The demand for walnut logs has varied considerably during the 1960's, but the general trend of log prices has been sharply upward. Rising prices with fluctuating demand indicate a scarcity of high-quality walnut, a need for more efficient and complete utilization of the walnut resource, and the necessity for reducing costs in domestic manufacturing of walnut products so they can remain competitive with substitutes and foreign products.*

29. Bolar, Max D. 1973. ORCHARD ESTABLISHMENT IN ARKANSAS. *In* Black walnut as a crop, Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For Serv. Gen Tech. Rep. NC-4, p. 79-80. North Cent. For. Exp. Stn., St. Paul, Minn.

*Although some black walnut orchards were started in earlier years, production planting for the multiple cropping of nuts, saw logs, and agricultural crops began in Arkansas Soil Conservation Districts in early 1972. Orchard sites were selected by use of the "Woodland Suitability Group" system as used by the Soil Conservation*

*Service. Krajicek's formula was used as a basis for spacing orchards. The planting techniques described assured good survival the first year despite a drought.*

30. Bonev, I. 1971. [PRODUCTION OF WALNUT GRAFTED SAPLINGS IN BULGARIAN POPULAR REPUBLIC.] Rev. For. Fr. 6: 609-614. [In French.]  
*Not seen.*

31. Borovskii, V. M. 1956. [SOILS OF THE WALNUT FORESTS OF SOUTHERN KAZAKHSTAN.] Tr. Inst. Pochvoved. Akad. Nauk Kaz. SSR 6: 32-43. [In Russian.]  
*The soils are thought to be young.*

32. Botman, K. S. 1968. [NATURAL RESTORATION OF SOIL FERTILITY ON TERRACES OF MOUNTAIN SLOPES.] Pochvovedenie 4: 77-84. [In Russian with English summary.]

*In the upper horizon of brown mountain forest soil in the Tashkent region, total porosity, percent content of water-stable aggregates, and percent contents of N and water-soluble humus in the upper horizon were greater under 65-yr-old Persian walnut or English oak planted on terraces than those in the soil between the terraces. Oak litter should be removed from the terrace once in 5 yr, but walnut litter should be retained.*

33. Boyette, Warren Giles. 1973. TREE CULTURE IN THE SOUTHEAST. *In* Black walnut as a crop. Black Walnut Symp., Carbondale Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 55-58. North Cent. For. Exp. Stn., St. Paul, Minn.

*Black walnut is scarce in hardwood state of the southeast but good potential exists for growing more quality timber. Recent silvicultural knowledge coupled with research findings in other regions make the growing of black walnut practical. Probb research results, and current recommendations are given for seed collection, nursery practices, site selection and preparation, plantings, and cultural practices. Silvicultural goals are stated and the problems needing further research are defined.*

34. Brenneman, Dwight L. 1971. GROWING WALNUT IN NORTH CAROLINA. South. Lumber 223(2776): 165-167.

*Transplanting of seedlings is preferred over direct seeding, especially when large seedlings, at least 3/4-in. caliper, are*

used. Planting on bedded sites and use of herbicides to control weeds are recommended.

35. Brunk, Eugene L. 1973. TREE IMPROVEMENT ACTION PROGRAMS--THE MISSOURI STORY. *In* Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 71-74, illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Missouri's black walnut tree improvement action program is cooperative between the USDA Forest Service and the Forestry Division of the Department of Conservation. The program consists of a long-term single tree selection-progeny test-seed orchard (SPSO) development phase, and a short-term phase. The short-term phase includes super-sized seedling production, seed collection, and seedling distribution to specific geographic zones, concurrent provenance testing, and seed production area (SPA) development.

36. Burke, Robert D., and Robert D. Williams. 1973. ESTABLISHMENT AND EARLY CULTURE OF PLANTATIONS. *In* Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 36-41, illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Presents a summary of information needed to establish and care for black walnut plantations. Subjects discussed include: how to choose a planting site, spacing, seedling selection and care, when and how to plant seedlings or seed, benefits from interplanted species, the need for and how to control weeds, when and how to prune to promote apical dominance, and clear stem pruning.

37. Butkov, A. Ia., U. Allanazarova, and Iu. Mirzaev. 1972. [EFFECT OF MINERAL FERTILIZERS ON DEVELOPMENTAL PHASES OF JUGLANS REGIA AT BOSTANLYK STATION.] Uzb. Biol. Zh. 6: 51-55. [In Russian.]

Not seen

38. Butkov, E. A. 1972. [GROWTH IN THICKNESS OF TRUNKS OF JUGLANS REGIA GROWN WITHOUT IRRIGATION AND AFFECTED BY MINERAL FERTILIZERS.] Uzb. Biol. Zh. 5: 41-43. [In Russian.]

Not seen.

39. Byrnes, W. R., J. E. Krajicek, and J. R. Wichman. 1973. WEED CONTROL. *In* Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 42-48. North Cent. For. Exp. Stn., St. Paul, Minn.

Weeds are unwanted plants that seriously compete with young black walnut for essential growth factors--space, light, moisture, and nutrients. Weed control is very important in plantations to assure successful establishment and early growth of walnut. Mechanical methods are feasible for weed control, but chemical control with pre- or postemergence herbicides is normally more effective and economical. Herbicides can be applied broadcast over entire areas or restricted to strips or spots adjacent to planted trees. Users of herbicides should be familiar with herbicide regulations and strictly adhere to precautions and directions listed on the label.

40. Cavender, Clarence C. 1973. UTILIZATION AND MARKETING OF SHELLS. *In* Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 77-78. North Cent. For. Exp. Stn., St. Paul, Minn.

For years the shells from black walnuts were considered a waste product; because 65 percent of the nut is shell, disposal was a costly and difficult problem. However, research and market potential have since shown that walnut shells can be used in a variety of ways. Today, black walnut shell is recognized as the best of all the nutshells and the demand has created as much of a shortage for black walnut shells as it has for the lumber and nut meats.

41. Cernilevskij, K. V. 1970. [INTRODUCTION OF JAPANESE SPECIES OF JUGLANS IN PODOLIA.] Bjul. Gl. Bot. Sada 77: 20-25. [In Russian.]

Gives data on the performance of *J. sieboldiana* and *J. cordiformis* in several plantations, avenues, etc., of various ages (the oldest 63 yr) in this part of the West Ukraine. Both species are very frost-hardy, grow well, regenerate naturally, and produce valuable wood. *J. cordiformis* has fruit of particularly high quality and could be extensively grown in regions where *J. regia* suffers from frost. As regards wood production, *J. nigra* is superior to *J. sieboldiana* and *J. cordiformis*.

42. Chaundhry, M. I., and N. K. Malik. 1972. OBSERVATIONS ON SOME IMPORTANT INSECT PESTS OF WALNUT. Pak. J. For. 22(3): 259-273, illus.

Gives notes on 50 insect species that were found to damage various parts of walnut (*Juglans regia*).

43. Chernoboi, G. M. 1971. [THE ROOT SYSTEM OF WALNUTS UNDER UNIRRIGATED CONDITIONS IN THE CRIMEAN STEPPE.] Tr. Gos. Nikitsk. Bot. Sada 52: 119-123. [In Russian with English summary.]  
Most walnut (*Juglans regia*?) roots spread horizontally in the 30- to 85-cm-deep soil layer and occupied an area 2.8 to 6.7 times larger than the crown. A planting distance of 15 to 18 m is recommended as the root system of walnuts reaches this diameter in 10- to 12-yr-old trees.
44. Chumak, I. V. 1970. [THE RHYTHM OF GROWTH AND DORMANCY IN *JUGLANS* SPECIES INTRODUCED IN Leningrad.] Bot. Z. 55: 1181-1185. [In Russian.]  
Periods of growth and dormancy were studied in three *Juglans* spp. in relation to winter hardiness. Visible growth in the winter-hardy *J. mandshurica* and *J. cinerea* started earlier (end of April to beginning of May) than in the less-hardy *J. regia* (middle to end of May). Intensive growth in the hardier species was observed during the first part of the growing season and in the less-hardy species during the second half.
45. Chumak, I. V., and I. N. Konovalov. 1971. [ACTIVITY OF RESPIRATORY ENZYMES IN INTRODUCED SPECIES OF *JUGLANS*.] In *Introduktsiya i ekologiya drevesnykh rastenii v Moldavii*, p. 22-36. [In Russian.]  
Gives data on the activity of o-diphenoloxidase and peroxidase in *J. mandshurica*, *J. cinerea*, and *J. regia* growing in Leningrad. In all three species, o-diphenoloxidase activity increased towards the end of the growing season, decreased after lignification of the shoots, and fell to zero during the period of winter dormancy.
46. Clark, F. Bryan. 1973. CULTURE: PAST, PRESENT, AND FUTURE. In *Black walnut as a crop*. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 30-32. North Cent. For. Exp. Stn., St. Paul, Minn.  
Black walnut culture began in the U.S. and Europe soon after colonization. Even so, commercial production of black walnut is still restricted primarily to the U.S. and Canada, but interest abroad continues. Present cultural practices are based on many years of experience and recent intensified research. Continuing research and additional experience are needed to improve practices. Research efforts are especially lacking in protection from insects and diseases and in economics.
47. Cook, O. F. 1923. EVOLUTION OF COMPOUND LEAVES IN WALNUTS AND HICKORIES. J. Heredity 14: 77-88.  
Numerous leaf variants of walnut are described in terms of reversion to a primitive state.
48. Cooper, Glenn A. 1971. BLACK WALNUT EXTRACTIVES AVAILABILITY IS INFLUENCED BY THAWING-TO-EXTRACTION TIME. For. Prod. J. 21(10): 44-45.  
The availability of black walnut heartwood extractives from green samples that have been frozen and thawed in the laboratory increases as the time between thawing and extraction increases. Care must be exercised to account for this variable when making extractive determinations.
49. Cooper, Glenn A. 1972. PREFREEZING REDUCES SHRINKAGE AND ALTERS DESORPTION IN BLACK WALNUT. For. Prod. J. 22(5): 54-60, illus.  
Heartwood and sapwood of black walnut, when prefrozen in the green condition at six temperatures from +14° to -320° F to test the effect of prefreezing on wood hygroscopic dimensional properties, and extractives. Prefreezing-to-drying time interval effects on board shrinkage were also measured. Induced shrinkage reductions and altered hygroscopicity were the combined effects of prefreezing on increased extractives but also on altered rheology. The greatest effect was induced by prefreezing at -110° F; storage time intervals after prefreezing did not affect shrinkage reductions.
50. Cooper, Glenn A., Calvin F. Bey, Ronald D. Lindmark, and Richard C. Schlesinger. 1972. BETTER HARDWOODS--FROM SEEDS TO LOGS AND MILLS TO MARKETS. South. Lumber 225(2800): 111-114, illus.  
Research at the Forestry Sciences Laboratory has resulted in increased black walnut growth, better stem characteristics, size selection criteria, greater seed supplies, better nursery management practices, utilization of woods residues, improved hardwood machining and drying techniques, new uses for hardwoods, and increased marketing and wood-use information.
51. Cooper, Glenn A., Eugene F. Landt, Ronald D. Lindmark, and Harold A. Stewart. 1973. CHANGING RESOURCE AND UTILIZATION. In *Black walnut as a crop*. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 10-11, illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Recent studies show that although the high-quality black walnut supply is diminishing, much untapped material is still available. The trees growing on nonforest land and logging residues can supply many of our needs. That low-quality material can be utilized has been demonstrated by woods residue recovery and conversion into products. Improved drying and machining techniques can increase efficiency of high-quality dimension part production, especially from low-quality raw material. Therefore, the manufacturer who practices close utilization can use the additional black walnut sources profitably.

2. Crandall, Bowen S., G. F. Gravatt, and Margaret Milburn Ryan. 1945. ROOT DISEASE OF CASTANEA SPECIES AND SOME CONIFEROUS AND BROADLEAF NURSERY STOCKS, CAUSED BY PHYTOPHTHORA CINNAMONI. *Phytopathology* 35: 162-180.  
*Isolates from root rot of seedling Juglans nigra and J. regia killed 40 percent of 5-yr-old J. nigra trees. In nursery soil known to be infected with P. cinnamoni, poorly drained sites should be avoided.*

3. Crandall, Bowen S., and Carl Hartley. 1938. PHYTOPHTHORA CACTORUM ASSOCIATED WITH SEEDLING DISEASES IN FOREST NURSERIES. *Phytopathology* 28: 358-360.

*In a North Carolina nursery, Juglans nigra seedlings infected with P. cactorum wilted and died shortly after emergence; approximately 50 percent were lost before emergence. The infections apparently had started as soon as, or before, the nuts had germinated and continued as a root rot.*

4. Dahms, K.-G. 1971. [WALNUT WOOD--STILL IN DEMAND. I. WHERE DO WALNUT SPECIES COME FROM AND HOW DO THEY DIFFER? II. USES, PROCUREMENT AND SUBSTITUTES.] *Holz-u. Kunststoffverarb.* 6(4,8): 358-368; 568-575.  
[In German.]

*I. Discusses the various species of Juglans, their distribution, differences, etc., and tabulates the distinguishing features of the wood of J. regia and J. nigra, and some information on the heartwood color and main growth regions of 16 species or varieties of Juglans. II. Discusses uses as solid wood and veneer, and the sources of Juglans imports into West Germany. A table is given listing 34 timbers (from Asia, America, Australia, and, mainly, Africa) that could be used as substitutes for Juglans.*

5. Davey, A. J. 1935. NOTE ON THE STRUCTURE OF THE EPICOTYL IN JUGLANS NIGRA. *New Phytol.*

34: 201-210.

*In the seedlings of certain species of Juglans (notably J. nigra) the early plumular leaves possess a double leaf trace with isolated central protoxylem. The traces of the first leaves are directly connected with root poles but the traces of a number of the succeeding leaves have no such connection and their protoxylem does not penetrate into the root.*

56. Deneke, F. J., and R. W. Funsch. 1970. EARLY NOTES ON BLACK WALNUT PROVENANCE TESTS IN KANSAS. *Kans. Acad. Sci. Trans.* 72(3): 404-405.

*After two growing seasons, survival for trees from southeastern sources was higher than that for local (Kansas) trees.*

57. Dickson, Richard E. 1971. THE EFFECTS OF SOIL MOISTURE, TEXTURE, AND NUTRIENT LEVELS ON THE GROWTH OF BLACK WALNUT. USDA For. Serv. Res. Pap. NC-66, 6 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

*Black walnut seedlings grown in a clay loam and sandy soil were subjected to two soil moisture regimes and three fertility levels. Fertilization increased growth only under moist conditions. Under drought, fertilization retarded growth in the sand. Nitrogen was the element primarily responsible for the greater growth under moist conditions.*

58. Duhan, K. 1970. [PRUNING AND CROWN FORMATION OF NUT TREES.] *Besseres Obst* 15: 107-109, illus.

*The disadvantages of allowing natural crown development on walnut trees are discussed, and advice is given on suitable methods of crown training, the time of pruning, and wound treatment.*

59. Dunmire, D. E., E. F. Landt, and R. E. Bodkin. 1972. LOGGING RESIDUE IS A SOURCE OF VALUABLE BLACK WALNUT DIMENSION. *For. Prod. J.* 22(1): 13-17, illus.

*Bolts 2 to 6-1/2 ft long were produced from black walnut logging residue obtained from operations in southern Illinois. Over 800 graded bolts were bolter-sawed into 1-1/2-in.-thick flitches, dried, surfaced to 15/16-in. thickness, and then diagrammed for determining yields of usable dimension parts. Yields averaged about 75 percent of the bolt scale (International 1/4 Inch Rule) in usable clear one-side dimension. About 70 percent of the dimension volume was in cutting lengths of 24 to 78 in.*

60. Elias, T. S. 1972. THE GENERA OF JUGLANDACEAE IN THE SOUTHWEST UNITED STATES. *J. Arnold Arbor.* 53(1): 26-51.  
 With sections containing descriptions and discussions of the family and the two genera *Carya* and *Juglans*, each section having its own bibliography.
61. Ellis, Gilbert R. 1972. PLASTIC MESH TUBES CONSTRICT BLACK WALNUT ROOT DEVELOPMENT AFTER TWO YEARS. *Tree Plant. Notes* 23(3): 27-28, illus.  
 Walnut seedlings grown in plastic mesh tubes had deformed roots after 2 yr due to the failure of the buried portion of the tube to break down. Even though early growth and survival of the seedlings are good, future development may be questioned because of the damaged root system.
62. Farmer, Robert E., Jr. 1973. VEGETATIVE PROPAGATION: PROBLEMS AND PROSPECTS. In *Black walnut as a crop. Black Walnut Symp.*, Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen Tech. Rep. NC-4, p. 66-70. North Cent. For. Exp. Stn., St. Paul, Minn.  
 Problems and opportunities in grafting, budding, and rooting black walnut are reviewed with emphasis on the role of these techniques in developing and using genetically improved stock. Better application of physiological principles should lead to increased production success with currently used grafting and budding procedures. Promising new information suggests that rooting will soon be a reliable technique. Some recommendations are made for future research and the development of propagation systems.
63. Farmer, Robert E., Jr., and G. C. Hall. 1973. ROOTING BLACK WALNUT AFTER PRETREATMENT OF SHOOTS WITH INDOLEBUTYRIC ACID. *Plant Propagator* 19(2): 13-14.  
 Etiolated shoots from juvenile *Juglans nigra* seedlings rooted with 58 percent success (range 0 to 100 percent for 80 ortets) following pretreatment with 1 percent indolebutyric acid in lanolin. Rooting success was better in June than in April or May.
64. Funk, David T. 1971. IDENTIFICATION AND PERFORMANCE OF *JUGLANS* HYBRIDS. *Diss. Abstr.* 32(12): 6761B-6762B.  
 The following traits of leaf morphology were selected for distinguishing *Juglans nigra*, *J. regia*, and putative hybrids between the two species: leaflets per leaf, marginal serrations per centimeter, position of the longest leaflet pair on the leaf, leaflet length: width index, and leaf pubescence. A weighted hybrid index was calculated that separates the parent species and can be used to classify most putative hybrids.
65. Funk, David T. 1973. GENETICS AND TREE IMPROVEMENT. In *Black walnut as a crop. Black Walnut Symp.*, Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen Tech. Rep. NC-4, p. 59-61. North Cent. For. Exp. Stn. St. Paul, Minn.  
 Recent progress of walnut genetic research and action programs has been good. It is possible to make considerable genetic gains for growth traits simply by using walnut planting stock of appropriate geographic origin. The prospects for vegetative propagation are now considerably improved for rooting of cuttings as well as grafting.
66. Geis, James W. 1973. BIOGENIC SILICA IN SELECTED SPECIES OF DECIDUOUS ANGIOSPERMS. *Soil Sci.* 116(2): 113-132, illus.  
 Particulate opaline silica accounted for 0.01 to 3.79 percent of the dry weight of leaves from 36 deciduous angiosperm tree and shrub species that included *Juglans nigra* and *J. cinerea*.
67. Geyer, W. A., and G. G. Naughton. 1971. GROWTH AND MANAGEMENT OF BLACK WALNUT (*JUGLANS NIGRA* L.) ON STRIP-MINED LANDS IN SOUTHEASTERN KANSAS. *Kans. Acad. Sci. Trans.* 73(4): 491-501, illus.  
 Black walnut plantations on partially leveled strip-mined lands have been successfully established from seed. Dominant and codominant trees, after 32 yr, are 6.1 in. d.b.h. and 33 ft; site index, 40 to 45 ft. After the 28th yr, low thinning and single-tree release more than tripled d.b.h. growth compared to unreleased trees.
68. Gott, Donald H. 1973. FEDERAL TRADE COMMISSION GUIDES AND THEIR EFFECTS ON THE CONSUMER. In *Black walnut as a crop. Black Walnut Symp.*, Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 23-25. North Cent. For. Exp. Stn., St. Paul, Minn.  
 Walnut and fine hardwoods consumer products now protected by Federal Trade Commission Guides are described. The Guides are interpreted, and the enforcement policies are explained; the consumer products still urgently in need of similar regulations are mentioned. Association activities in furniture case goods surveys and tag and label promotions are also described.

69. Graves, Arthur H. 1923. THE MELANCONIS DISEASE OF THE BUTTERNUT. *Phytopathology* 13: 411-435, illus.  
*The fungus is a weak parasite, entering twigs through previous wounds. In trees that are previously weakened, the fungus makes rapid progress; otherwise the disease advances slowly. The Japanese walnut is also particularly susceptible.*
70. Grey, Gene W. 1973. SEVEN YEARS OF GROWTH. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 4-6. North Cent. For. Exp. Stn., St. Paul, Minn.  
*The 7 yr since the Black Walnut Workshop have shown a continued decline in walnut log quality. The application of new research, tree improvement programs, and intensive culture give hope, however, that this downward curve may soon flatten. The walnut industry must also address itself to problems of marketing, economics, seedling production, and even social areas.*
71. Grey, Gene W., and Gary G. Naughton. 1971. ECOLOGICAL OBSERVATIONS ON THE ABUNDANCE OF BLACK WALNUT IN KANSAS. *J. For.* 69(10): 741-743, illus.  
*Observations along the prairie-forest transition zone show that the high ratio of woodland edge to woodland area creates conditions of early forest succession that are highly favorable to black walnut and other early stage intolerant tree species.*
72. Grosse, W., and H. Witzache. 1973. [IDENTIFICATION AND LOCALISATION OF TRYPTOPHAN SYNTHETASE IN SEEDS OF JUGLANS REGIA L.] *Planta* 111(1): 65-71. [In German.]  
*Not seen.*
73. Gupta, S. R., B. Ravindranath, and T. R. Seshadri. 1972. POLYPHENOLS OF JUGLANS NIGRA. *Phytochemistry* 11(8): 2634-2636.  
*Apart from juglone, the bark of J. nigra contains  $\alpha$ -hydrojuglone-4-glucoside, myricetin, myricitrin, sakuranetin, sakuranin, and neosakuranin. These compounds appear to be absent in the sapwood and heartwood.*
74. Gutenev, V. I. 1970. [GRAFTING WALNUTS.] *Sadovodstvo* 10: 27-28. [In Russian.]  
*Scions 30 cm long with two vegetative buds were taken from the lower part of mature 1-yr-old shoots of young Juglans regia trees and crown grafted in April on the walnut seedlings 4 to 6 m tall. The scions were taken in either October or March but only the latter grew satisfactorily. Of five grafting methods tried, only modified rind grafts gave a high (83 percent) proportion of takes.*
75. Hall, H. M. 1918. WALNUT POLLEN AS A CAUSE OF HAY FEVER. *Science* 37: 516-517.  
*Juglans hindsii in California.*
76. Hammons, R. Dwain. 1973. UTILIZATION AND MARKETING OF NUTS. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 75-76. North Cent. For. Exp. Stn., St. Paul, Minn.  
*About 60 percent of commercially processed black walnut kernels are repacked for retail sale to housewives, another 30 percent is used in ice cream, 5 percent in commercial baking, and 5 percent in candy manufacture. Sterilization of nutmeats is important in ice cream manufacture. No government standards have ever been established for nutmeat sizes or quality, except for bacterial control. Recently, smaller-sized nutmeats including meal have been used for retail distribution and ice cream. The annual supply of salable kernels has been reduced 40 percent in the last decade by cutting of good nut-producing trees for lumber, by disease, and by indiscriminate herbicide spraying.*
77. Hansche, P. E., V. Beres, and H. I. Forde. 1972. ESTIMATES OF QUANTITATIVE GENETIC PROPERTIES OF WALNUT AND THEIR IMPLICATIONS FOR CULTIVAR IMPROVEMENT. *Am. Soc. Hortic. Sci. J.* 97(2): 279-285.  
*Heritabilities and phenotypic correlations among 18 traits of English walnut were estimated from measurements obtained over 14 yr from 38 parent and over 2,000 progeny trees. Heritabilities are above 80 for leafing date, first shedding of pollen, receptive date of pistils, harvest date, shell thickness, all nut and kernel measurements, and weight. All measures of nut and kernel size are highly correlated; they negate the practical value of measuring more than one of these traits. Selection of these traits correlated with yield appears to be an effective and economical means of achieving a reasonable rate of genetic gain in yield. Probably the key trait in this regard is fruitfulness of laterals.*
78. Harlow, W. M. 1930. THE FORMATION OF CHAMBERED PITH IN THE TWIGS OF BUTTERNUT AND BLACK WALNUT. *J. For.* 28: 739-741.  
*Chambering does not take place until after extension growth of the twig has ceased, or nearly so.*

79. Harris, R. W. 1971. THE CONTROL OF TRUNK SPROUTS ON LANDSCAPE TREES. *Int. Shade Tree Conf. Proc.* 46: 57a-63a.  
*In spraying trials, both NAA and 2,4,5-T effectively reduced the percent of new epicormics on all the trees treated, whether they were dormant or had begun new growth. Picloram was effective on the four species tested, especially Juglans nigra, but when applied at 0.5 and 1 percent it killed 3-yr-old poplars and caused malformation and chlorosis in willows. NAA had no adverse effects, but 2,4,5-T caused some epinasty of the leaves in willows and poplars. With all compounds used, spraying dormant trees was less effective in reducing the growth of epicormics in J. nigra, olive, poplar, and willow than in Eucalyptus, Pyrus kawakamii, Sequoia sempervirens, and Lagerstroemia indica. Responses to different concentrations varied with species. There was little translocation of any compound, even at the high rates used. For general use, 0.5 to 1 percent NAA, applied to runoff, is recommended.*
80. Harris, R. W., R. M. Sachs, and R. E. Fissell. 1971. CONTROL OF TRUNK SPROUTS WITH GROWTH REGULATORS. *Calif. Agric.* 25 (11): 11-13, illus.  
*Regrowth of trunk sprouts on eight of nine species (including Juglans hindsii) treated with growth regulators was reduced by 85 percent, as compared with untreated trees in these tests. The sprouts that did grow on treated trunks were only one-tenth to one-third as long as sprouts from untreated trunks. There was very little translocation of the growth regulators from the regions of application.*
81. Hiller, C. H., F. Freese, and D. M. Smith. 1972. RELATIONSHIPS IN BLACK WALNUT HEARTWOOD BETWEEN COLOR AND OTHER PHYSICAL AND ANATOMICAL CHARACTERISTICS. *Wood & Fiber* 4(1): 38-42.  
*Relationships in black walnut heartwood between color and specific gravity, extractive content, and anatomical characteristics were explored. Percent luminance, color brightness, was significantly related to extractive content and to the combination of extractive content and some of the measures of wood density. It was found that trees from Indiana compared with those from Missouri differed significantly in the following wood characteristics: lower extractive content, higher proportion of fibrous tissue with thinner cell walls, and smaller vessel lumens.*
82. Holt, Harvey A., and Jack E. Voeller. 1972. EFFECT OF VEGETATION CONTROL ON ESTABLISHED BLACK WALNUTS. *Arkansas Farm Res.* 21(1): 8.  
*Chemical herbicides were applied to an 8-by 8-ft area around 13-yr-old 'Thomas' black walnut trees. Branch growth and nut quantity, weight, and size were all increased by chemical weed control.*
83. Holt, Harvey A., and Jack E. Voeller. 1973. VEGETATION MANAGEMENT INCREASES PRODUCTION IN NUT ORCHARD. In *Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 81-83. North Cent. For. Exp. Stn., St. Paul, Minn.*  
*Tree growth, nut production, nut weight, and nut size were substantially increased by controlling vegetation with herbicides. The response to varying degrees of vegetation control has been consistent for the first 2 yr of the study. Because of the magnitude of response, controlling vegetation appears to be a cost of orchard management that will prove profitable over the long run.*
84. Hryshko-Bohmenko, B. K. 1970. [ON PHENOMENON OF DICHOGAMY IN JUGLANS L.] *Akad. Nauk. Ursr. Introd. Aklim. Rosl. Ukr.* 4: 158-165. [In Ukrainian.]  
*Not seen.*
85. Jaró, Z., and S. Horváth. 1960. [THE CALCIUM CONTENT OF FOREST LITTER AND ITS IMPORTANCE.] *Erdész. Kut.* 56: 93-103. [In Hungarian.]  
*CaO percent in leaves was lowest in early spring and highest at leaf fall. Highest contents occurred in Juglans nigra, Robinia pseudoacacia, and Populus tremula, and the lowest in Quercus sp. and Fagus silvatica. For mixed stands on acid soils, the highest amounts of easily decomposable litter of high Ca contents are provided by Tilia sp., Acer campestre, and Carpinus betulus.*
86. Jones, H. C., III, and J. W. Curlin. 1968. THE ROLE OF FERTILIZERS IN IMPROVING THE HARDWOODS OF THE TENNESSEE VALLEY. In *Forest Fertilization: Theory and Practice For. Fert. Symp. 1967, Tenn. Val. Auth., Knoxville, Tenn., p. 185-190.*  
*Discusses results from fertilizing several hardwood species in the Tennessee Valley, and describes plans for a fertilization study with 17 families of black walnut as part of a tree improvement program.*

87. Jovanović, B., and V. Valčić. 1970. [PHYTOCENOSIS OF WALNUT (JUGLANS REGIA L.) IN DJERDAP REGION.] Inst. Sumar. Drvnu. Ind. Zb. 9: 201-213. [In Croatian.]  
Not seen.
88. Kaeiser, Margaret, and David T. Funk. 1972. STRUCTURAL CHANGES IN WALNUT GRAFTS. North. Nut Grow. Assoc. Annu. Rep. 62(1971): 90-94, illus.  
Twenty-two scion-rootstock combinations of *Juglans* species and hybrids have been grafted, and all appear to be at least partially compatible. *J. sieboldiana* seems to be more compatible with other walnuts when used as a rootstock than when used as a scion. In 5-yr-old grafts of *J. regia* x *nigra* on *J. nigra*, the bark tends to grow faster on the stock than on the scion.
89. Kahn, M. S. 1969. FUNGAL ASSOCIATES OF JUGLANS NIGRA L. Diss. Abstr. 29B(12, Part 1), (4471).  
In greenhouse studies, walnut seedlings were grown in clay pots, in a rhizosphere inoculated with *Fusarium* sp., *Cylindrocarpum radialis*, *Rhizoctonia* sp., and two unidentified fungi (all originally isolated from walnut roots), individually and in all combinations, to determine whether the fungi are beneficial, neutral, or pathogenic parasites of the host; three nutrient levels were also studied. After 16 weeks, plants were harvested, root samples were examined microscopically, and the dry weight and the percent and weight of N and P of whole plants were determined; the color and growth of the seedlings were also assessed. Results suggest that the reactions of host and fungus differ when only one fungus is present from those when two or more are present.
90. Khattak, G. M. 1969. EARLY RESPONSE OF PLANTED BLACK WALNUT TO SITE MODIFICATION. Diss. Abstr. 30B, 1, (12).  
The treatments comprised: wind protection with snow fences, mulching with fresh hardwood chips, application of fertilizer, and irrigation (weekly surface application of 7.5 l/tree unless 2.5 cm of natural precipitation had fallen during the previous week). The effects of the treatments on soil moisture, amounts of K in the soil, and of K and N in leaves, leaf area, leaf water tension, and height and diameter growth in the first 2 yr are discussed. Direct planting of container-grown black walnut is recommended for farm forestry.
91. Khrichenko, E. M. 1971. [THE CHARACTERISTICS OF WALNUT TREE GROWTH ON THE SLOPES OF THE CENTRAL CAUCASUS FOOTHILLS.] Tr. Sev. Lesn. Opytn. Stn. 9: 111-122. [In Russian.]  
Walnut trees (*Juglans regia*?) planted on gentle and steep (terraced) slopes facing north and south were studied in the 7th year after planting. The trees grew well on several soil types and in monoculture, but not in mixed plantings. Tree height on the southern slopes was 1.3 to 1.5 times less than on the northern slopes, and trees on the outer part of the terraces grew better than those on the inner part.
92. King, Alan. 1973. FORAGE AND TREES. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 86-87. North Cent. For. Exp. Stn., St. Paul, Minn.  
The use of walnut trees in a concept known as multiple cropping more fully utilizes the productivity of the land. Growing forage in the interim required for trees to mature seems to offer a logical use of medium- to high-cost cropland while sustaining trees as a secondary crop. The trees will gradually change from the secondary crop to the primary crop as they grow in size.
93. Krajicek, John E. 1972. SPACING AND PRUNING BLACK WALNUT TO PRODUCE BOTH NUTS AND LUMBER. North. Nut Grow. Assoc. Annu. Rep. 62(1971): 95-98, illus.  
Many landowners are interested in growing black walnut only for its nut production. Through careful control of spacing, prudent thinning, corrective pruning, and frequent but conservative clear-length pruning of the walnut trees, the nut grower should also be able to produce high-value sawlogs. Proper spacing and methods of pruning are discussed.
94. Krajicek, John E., and Robert D. Williams. 1971. CONTINUING WEED CONTROL BENEFITS YOUNG PLANTED BLACK WALNUT. USDA For. Serv. Res. Note NC-122, 3 p. North Cent. For. Exp. Stn., St. Paul, Minn.  
Cultivation, atrazine, and simazine were used for weed control 1, 2, and 3 yr following planting of black walnut in Iowa and Indiana. In Iowa, 2 or more years of weed control resulted in the best seedling growth, but in Indiana 3 yr proved best. Method of weed control had no significant effect on seedling growth in Iowa, but chemical control resulted in better growth than cultivation in Indiana. After 5 yr in the Iowa planting, the walnut seedlings that had received weed control for 2 or 3 yr continued growing faster than those that had received only

1 yr of weed control, even though no weed control was done in at least the last 2 yr.

95. Krapf, B. 1971. [FLOWERING BIOLOGY AND FRUIT SETTING IN WALNUT TREES....] Schweiz. Z. Obst-u. Weinbau 107(11): 341-347, illus. [In German.]

A discussion of walnut seed production as influenced by dichogamy, apomixis, vegetative growth, and other factors.

96. Kribs, David A. 1927. COMPARATIVE ANATOMY OF THE WOODS OF JUGLANDACEAE. Trop. Woods 12: 16-21.

The results of this investigation indicate that the members of Juglandaceae comprise a "natural" family. They also indicate that there are only four distinct genera: *Carya*, *Platycarya*, *Juglans*, and *Engelhardtia*. *Pterocarya* belongs with the division of *Juglans* of which *J. cinerea* may be considered the type, and *Alfaroa* belongs with the *Oreomunnea* section of *Engelhardtia*.

97. Kung, Fan H. 1973. DEVELOPMENT AND USE OF JUVENILE-MATURE CORRELATION IN BLACK WALNUT TREE IMPROVEMENT PROGRAM. South. For. Tree Improv. Conf. Proc. 12: 243-249.

Cross section discs were cut at predetermined intervals from 19 black walnut trees. Growth rings on each disc were measured. Diameter, height, and volume at various ages were determined by stem analysis. Character used for early selection should have high juvenile-mature correlations. The earliest age for selection should maximize the product of the juvenile-mature correlation and the selection differential at that age.

98. Lagerstedt, H. B. 1972. A REVIEW OF WALNUT POLLINATION PROBLEMS AND THEIR SOLUTION IN OREGON. North. Nut Grow. Assoc. Annu. Rep. 62(1971): 30-33.

Seasonal climatic variation, local site conditions, and tree age all interact to affect the year-to-year suitability of prospective pollenizers to be used in walnut orchards.

99. Landt, Eugene F., and Robert E. Phares. 1973. BLACK WALNUT...AN AMERICAN WOOD. USDA For. Serv. Am. Woods Leaflet. FS-270, 7 p., illus.

Black walnut, one of America's most valuable tree species, has been prized since colonial times for furniture, interior finish, and gunstocks. Its nuts have a distinctive flavor that is relished by many. The decay-resistant heartwood is chocolate

brown and occasionally has darker, sometimes purplish, streaks. The sapwood is almost white. It is straight-grained, strong, hard, heavy, stiff, easily worked with tool, and stays in place well after seasoning. Because of heavy use and wasteful cutting over the years, choice black walnut trees have become scarce and the price of logs has skyrocketed.

100. Lange, A. H., and J. C. Crane. 1967. THE PHYTOTOXICITY OF SEVERAL HERBICIDES TO DECIDUOUS FRUIT TREE SEEDLINGS. Am. Soc. Hortic. Sci. Proc. 90: 47-55, illus.

Fifteen herbicides were applied to the roots of six deciduous fruit tree species growing in nutrient-fed sand. Of the pre-emergence herbicides evaluated in this greenhouse test, simazine, diuron, and prometryne appeared to be safest on 'Northern California' black walnuts. Based on the results obtained, the postemergence herbicides dalapon, amitrole, and paraquat have promise for use in orchard crops. Walnuts were severely stunted at the 50 p/p amitrole rate, with pronounced chlorosis in young leaves. Dicamba and picloram are expected to prove too hazardous for orchard use.

101. Langrová, V., and Z. Sladký. 1971. THE ROLE OF GROWTH REGULATORS IN THE DIFFERENTIATION OF WALNUT BUDS (*JUGLANS REGIA* L.). Biol. Plant. 13(5,6): 361-367.

The character of endogenous regulators of walnut buds was followed by means of bioassays in the course of vegetation. It was ascertained that a rise in the level of gibberellin-like substances precedes the sprouting of buds. The origination of new buds in the axil of young leaves is accompanied by a fall in the level of auxins, a low gibberellin content, and the presence of inhibitors. In this situation the primordia of staminate catkins are differentiated in the basal buds. The vegetative buds, which are formed in the axils of further leaves, stop developing because of the accumulating inhibitors. Toward the close of vegetation the primordia of pistillate flowers originate in terminal buds and their differentiation is accompanied by a substantial rise in the level of auxin-like substances, while some of the inhibitors keep asserting themselves. On the basis of these findings, we have tested the possibility of affecting the differentiation of staminate primordia and of vegetative buds by the exogenous application of selected regulators. Spraying young leaves with IAA and MH solution

will increase the number of vegetative buds in the twigs. A later spray of other twigs by TIBA and GA<sub>3</sub> solutions will increase the number of staminate buds.

102. Lebedinova, N. S. 1961. [MOISTURE REGIME OF DARK-BROWN FOREST SOILS OF WALNUT FORESTS.] Pochvovedenie 5: 21-33. [In Russian with English summary.]

*In the walnut forests of southern Kirgizia, soil-moisture reserves increased in autumn through spring and decreased gradually in summer. The maximal and minimal moisture reserves under forest were greater than in the old cultivated soils that interrupt the continuity of the forest.*

103. Lebedinova, N. S. 1968. [MOISTURE REGIME OF DARK BROWN SOILS UNDER A CANOPY OF DIFFERENT TYPES OF WALNUT FORESTS IN FERGAN.] Pochvovedenie 12: 32-41. [In Russian with English summary.]

*In the walnut forests of south Kirgizia, evaporation exceeds precipitation and in the dry, second half of the vegetative period the trees depend entirely on soil-moisture reserves. This dependence is particularly great for Persian walnut because of its long vegetative period. In this mountainous region, Persian walnut receiving only natural moisture grows best where soil moisture derived from precipitation is supplemented by perched water tables or artesian water. Where soil-moisture reserves are insufficient, irrigation is necessary for good growth.*

104. Lindsey, Steven E. 1973. COST AND INCOME TREATMENT ON SMALL WOODLANDS. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 101-105. North Cent. For. Exp. Stn., St. Paul, Minn.

*Universal demand and high value commonly associated with the sale of walnut timber may result in an excessive tax burden to farmers/woodland owners. It is the purpose of this report to present the proper treatment of incurred costs and the use, benefits, and regulations of long-term capital gains and losses as related to the small, individual timber owner.*

105. Losche, Craig K. 1972. VERTICAL TILLAGE FAILS TO IMPROVE BLACK WALNUT SEEDLING GROWTH ON POORLY DRAINED SITE. Tree Plant. Notes 23(1): 7-9.

*A soil modification method tested in*

*southern Illinois to determine whether internal drainage of floodplain soils could be improved to promote better black walnut seedling growth provides no practical evidence of growth acceleration after four seasons.*

106. Losche, Craig K. 1973. BLACK WALNUT GROWTH BETTER ON DEEP, WELL-DRAINED BOTTOMLAND SOILS. USDA For. Serv. Res. Pap. NC-154, 3 p. North Cent. For. Exp. Stn., St. Paul, Minn.

*Site requirements of 25-yr-old plantation-grown black walnut on floodplains in southern Illinois were studied. Depth to a gravel layer was the only soil factor that significantly influenced height growth. There was a relationship between internal soil drainage and height growth.*

107. Losche, Craig K. 1973. SELECTING THE BEST AVAILABLE SOILS. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 33-35. North Cent. For. Exp. Stn., St. Paul, Minn.

*The relationship between observable soil characteristics and black walnut growth is discussed, and a procedure is presented for using soil and topographic factors to select and evaluate areas for growing black walnut. Also, the influence of soil characteristics on the need for and extent of various cultural practices is examined.*

108. Losche, C. K., W. M. Clark, E. E. Voss, and B. S. Ashley. 1972. GUIDE TO THE SELECTION OF SOIL SUITABLE FOR GROWING BLACK WALNUT IN ILLINOIS. Northeast. Area State and Priv. For. Spec. Pub., 38 p.

*The soil series occurring in Illinois are classified as to their suitability for growing black walnut. Three categories--suitable, questionable suitability, and unsuitable--are used to assist Illinois Division of Forestry district foresters in selecting the better sites available for this valuable hardwood.*

109. Losche, Craig K., and Robert E. Phares. 1972. SILTATION DAMAGE IN A BLACK WALNUT PLANTATION. J. Soil and Water Conserv. 27(5): 228-229, illus.

*After unusually heavy rainstorms in the spring and fall of 1970, over 2,600 tons of silt were deposited over 2.8 acres in a black walnut plantation in north-central Missouri. This silt deposit caused extensive mortality and growth reduction in the*

- plantation. Walnut mortality and diameter-growth reduction were closely related to thickness of the silt deposit. Deposition of silt in the spring was more detrimental to walnut growth than siltation in the fall just preceding the winter dormant season. This episode demonstrates the need for erosion-control practices and for more critical site evaluation when selecting a planting area for this valuable hardwood species.
110. Loucks, William L., and Ray A. Keen. 1973. SUBMERSION TOLERANCE OF SELECTED SEEDLING TREES. *J. For.* 71(8): 496-497.  
Ten deciduous species of tree seedlings were completely submerged during June and July. Two weeks' submergence caused little damage, but black walnut was intolerant of 4 weeks under water, being the only species to suffer complete mortality.
111. Lowe, W. J., W. F. Beineke, and E. J. Lott. 1973. PROPAGATION TECHNIQUES FOR BLACK WALNUT. *Purdue Univ. Coop. Ext. Serv. Notes on For. and Wood-Use F-64*, 6 p., illus.  
Describes techniques suitable for grafting black walnut before and after growth of the rootstock has started.
112. McKay, J. W. 1972. WALNUT HYBRIDS AT BELTSVILLE, MARYLAND. *North. Nut Grow. Assoc. Annu. Rep.* 62(1971): 34-38, illus.  
 $F_1$  hybrids between *Juglans regia* and *J. nigra* tend to be sterile and produce very few nuts.  $F_2$  hybrids tend to grow vigorously and are slow to bear. Although no seedling worthy of propagation as a nut variety has been found among 125  $F_2$  hybrids that have fruited, there appears to be sufficient variability to justify fruiting the remaining 275 seedlings.
113. McMillan-Browse, P. D. A. 1971. PROPAGATION OF WALNUTS AND WING NUTS. *Gard. Chron.* 170(12): 20-21, 23.  
Raising from seed and propagation by budding and grafting for *Juglans* spp. is described with particular reference to work at East Malling Research Station.
114. Maliga, P., and J. Tamási. 1957. [ROOT FORMATION OF THE WALNUT TREE IN SANDY SOIL.] *Acad. Hortic. Bp. Ann.* 21(4): 16. [In Hungarian with Russian and English summaries.]  
Over 87 percent of the roots were located in the 40 to 220 cm layer of soil (60 percent at 40 to 60 cm) and about 12 percent at a depth of 20 to 40 cm.
115. Manušev, B. 1970. [STUDIES ON SOME METHODS OF GRAFTING WALNUTS IN THE REGION OF FACE.] *Jugosl. Vocarstvo* 4(13): 51-59, illus. [French summary.]  
Splice grafting green components in late May or early June was unsatisfactory, averaging over 3 yr only 15.6 percent take. Patch budding in June or July had 47.5 percent success, but patch budding with dormant buds in August showed less than 2 percent take.
116. Martin, G. C., H. A. Abdel-Gawad, and J. Weaver. 1972. THE MOVEMENT AND FATE (2-CHLOROETHYL) PHOSPHONIC ACID IN WALNUT. *Am. Soc. Hortic. Sci. J.* 97(1): 51-54, 1 illus.  
 $^{14}C$ -Ethephon applied to a walnut leaf, penetrated and was translocated rapidly in young plants, but more slowly in older plants. The compound was translocated to the kernel at higher levels when applied to a leaf than when applied to the hull, but in both cases the levels of activity were low. Between 5 and 7 days after application the radioactivity in the kernel decreased markedly.  $^{14}C$ -Ethephon in the leaves, hull, shell, and kernel was metabolized, but no side products remained in the plant tissue that could be detected by the techniques employed.
117. Massengale, Robert. 1973. THE SIGNIFICANCE OF LOG AND TREE GRADING SYSTEMS. Black walnut as a crop. *Black Walnut Symposium*, Carbondale, Ill., Aug. 14-15, 1973. *USD. For. Serv. Gen. Tech. Rep. NC-4*, p. 28-29, 1 illus. North Cent. For. Exp. Stn., St. Paul, Minn.  
Everyone who owns or plans on owning a walnut tree is interested in the value of that tree. Value is generally measured in terms of tree or log grades. The number, type, and location of defects are common to all grading systems. Defects generally fall into two categories: (1) those that are natural or caused by some external force upon the tree, and (2) those that are created by man in his manufacturing or processing of the tree. Understanding defects and their importance to the manufacturing of the final product will help the timber landowner better understand the value of his resource and will guide him toward using the proper forest management practices.
118. Maurer, K. J. 1971. [SUN SCORCH DAMAGE IN WALNUTS AFTER THINNING OUT OLD CROWNS.] *Erwerbsobstbau* 13: 13-14, illus. [In German.]  
Illustrations show bark damage by sun scorch and the occasional invasion of the

wounds by *Schizophyllum commune*. Recommended measures to prevent damage comprise thinning out the crowns over several years, pruning and training grafted trees to form small open crowns, and cleaning the wounds and treating with a wound-healing preparation.

119. Mazur, O. P., and N. M. Shemokhanova. 1965. [EFFECT OF FOREST SOIL ON DEVELOPMENT OF SEEDLINGS OF PERSIAN WALNUT IN THE FIRST YEAR OF LIFE.] *Izv. Akad. Nauk. Ser. Biol.* 3: 428-431. [In Russian with English summary.]

*Inoculating irrigated meadow-bog serozem with soil from a forest of Persian walnut increased formation of endotrophic mycorrhizae in the seedlings and also increased their growth.*

120. Micke, G. 1973. [CULTIVATION OF WALNUT IN FORESTRY OF GERMAN DEMOCRATIC REPUBLIC.] *Soz. Forstwirtschaft.* 23(5): 150-151. [In German.]

*Not seen.*

121. Miller, William E. 1973. INSECTS AS RELATED TO WOOD AND NUT PRODUCTION. In *Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 91-96. North Cent. For. Exp. Stn., St. Paul, Minn.*

*The more important insects affecting wood and nut production are named and briefly discussed. Wood crop insects may retard or impair incremental growth by retarding or spoiling it. Walnut production practices may at times unintentionally increase insect numbers. Nonchemical control or regulation measures are highlighted. New information about insects is not keeping pace with progress in other aspects of walnut production technology.*

122. Millikan, D. F. 1972. PROPAGATION OF *JUGLANS* SPECIES BY FALL GRAFTING. *North. Nut Grow. Assoc. Annu. Rep.* 62(1971): 41-44, illus.

*Selected varieties of Juglans species can be propagated by bench grafting in the fall followed by a 3- to 4-week callusing period at 26° C in moist, sterilized sawdust. The grafts are then stored at 2° C until the completion of the dormancy period when they can be planted. Scionwood must be mature and the relative humidity in storage sufficiently high to prevent desiccation.*

123. Milovanova, L. V., and I. P. Radušinskaja. 1969. [THE BIOCHEMICAL CHARACTERISTICS OF

THE MOLDAVIAN FORMS OF WALNUT AND ALMOND.] *Tr. Mold. Nauchn.-Issled. Inst. Sad. Vinograd. Vinodel.* 15: 292-298. [In Russian.]

*During 5-yr studies the oil content in 44 walnut forms and the protein, P, and K contents in 15 of them, were determined and are tabulated.*

124. Muller, C. H. 1969. ALLELOPATHY AS A FACTOR IN ECOLOGICAL PROCESS. *Vegetatio* 18: 348-357.

*Not seen.*

125. Munteanu, C., and M. Kalo. 1971. [SOME BIOCHEMICAL ASPECTS OF PARASITISM IN LORANTHACEAE. AMOUNT OF TOTAL AND REDUCING SUGAR IN *VISCUM ALBUM* L. AND IN ITS HOST, *JUGLANS NIGRA* L.] *Cluj Univ. Babes-Bolyai Stud. Ser. Biol.* 16(2): 69-75. [In Romanian with English summary.]

*Seasonal variations of total and reducing sugar are tabulated for stems and leaves of Viscum album L. and those of its host plant, Juglans nigra L. Differences in reducing sugar in parasite and host plant, on one hand, and in parasite and in control plant on the other were more pronounced than the variations in the total sugar. A comparison of the sugar content in mistletoe parasitizing different hosts revealed that the nature of the host had an evident influence upon the carbohydrate content of the parasite.*

126. Naughton, Gary G. 1973. EVALUATING ECONOMIC MATURITY OF INDIVIDUAL TREES. In *Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 97-100. North Cent. For. Exp. Stn., St. Paul, Minn.*

*The decision to cut a walnut tree should be carefully weighed in terms of its present value as opposed to its future value. Maximum economic yield is possible when each tree is evaluated as an individual in terms of its own quality, size, and growth rate. Instructions are given for the use of a graph to find the compound earning rate and examples show the effects of pruning and release.*

127. Nedev, N. V. 1970. [SOME PROBLEMS OF WALNUT GRAFTING BY BUDDING IN SPRING.] *Grad. Lozar. Nauk.* 7(2): 3-9. [In Bulgarian with French and Russian summaries.]

*In trials carried out in 1964 and 1966, it was shown that success in spring budding of walnuts depended chiefly on the temperature and on the development of the rootstocks. The air temperature should be above 12 to 14° C, and the rootstocks should*

be growing and with bark easily separable from the wood. The greatest degree of success was obtained using bud-sticks that had been selected earlier in the year and stored. Shortening the rootstocks had no effect on bud take, but favorably affected the growth of the scion shoots.

128. Nedev, N. V. 1971. [SEVERAL PROBLEMS ON ROOTSTOCKS OF WALNUTS.] *Ovoshtarstvo* 18(3): 11-14.

*Not seen.*

129. Nedev, N. V. 1972. [EFFECT OF SCIONS IN COMMON, EASTERN BLACK, AND MANCHURIAN WALNUTS ON ROOTSTOCKS DURING FIRST AGING PERIOD AND AT BEGINNING OF SECOND AGING PERIOD. I. GROWTH BEHAVIOR OF TREES.] *Grad. Lozar. Nauk.* 9(8): 15-24. [In Bulgarian.]

*Not seen.*

130. Nedev, N. V. 1973. [EFFECT OF SCION IN ROOTSTOCKS OF COMMON, EASTERN BLACK, AND MANCHURIAN WALNUTS DURING FIRST AGING PERIOD AND AT BEGINNING OF SECOND AGING PERIOD. II. REPRODUCTIVE BEHAVIOR OF TREES.] *Grad. Lozar. Nauk.* 10(1): 3-8. [In Bulgarian.]

*Not seen.*

131. Nedev, N. V., and Kh. Baev. 1971. [DEVELOPMENTAL FEATURES OF GENERATIVE ORGANS OF SEVERAL VARIETIES OF WALNUTS.] *Grad. Lozar. Nauk.* 8(7): 3-8. [In Bulgarian.]

*In 17-yr-old grafted trees of two walnut varieties, secondary flowering was observed and both male and female flowers occurred in the same inflorescences. This is a varietal characteristic occurring mainly where the male flower buds are killed by frost.*

132. Nedev, N., P. Prodanski, and S. Dzhondzhorova. 1971. [THE PROTEIN CONTENT AND AMINO ACID COMPOSITION OF KERNELS IN SOME VARIETIES OF WALNUT, *JUGLANS REGIA*.] *C. R. Acad. Sci. Agric. Bulg.* 4(3): 295-298. [In Russian.]

*The raw protein contents in the kernels of three walnut cultivars are given. Of the essential amino acids, lysine, threonine, and methionine + valine occurred in the highest concentrations.*

133. Nelson, Neil Douglas. 1973. EFFECTS OF AMOUNTS OF PARENCHYMA ON QUANTITY OF PHENOLIC EXTRACTIVES PRODUCED DURING FORMATION OF HEARTWOOD IN *JUGLANS NIGRA* AND *QUERCUS RUBRA*. Ph.D. Diss. on file in the Dep. of For., Univ. of Wis., Madison, Wis. 249 p., illus.

*Amount of total heartwood extractives varied substantially between trees of *J. nigra*; this variation was not related to rate of radial growth. Amounts of total, and total phenolic, heartwood extractives exhibited marked variation radially within trees; this variation was strongly and positively related to the number of rings from pith. Relative volumes of parenchyma varied substantially between and within tree. Between-tree differences were related to rate of radial growth in only a few cases. Relative volumes of parenchyma were not related to between-tree variation in amount of total extractives. By eliminating amount of parenchyma as a control mechanism, the results pointed to metabolic control of rate and duration of aromatic biosynthesis within each parenchyma cell as being the primary determinant of amount of phenolic extractives produced. Geneticists should not attempt to control the amount of heartwood extractives in hardwood species by selection for high or low relative volumes of parenchyma.*

134. Nenyukhin, V. N. 1972. [VARIABILITY OF NUTS OF *JUGLANS REGIA* L. WITHIN ITS POPULATION.] *Rastit. Resur.* 8(1): 60-68. [In Russian.]

*Marked polymorphism was observed in the nuts of an artificial population of *J. regia* from different plantings. A relationship was found between the age of the plantings and nut and kernel weight and shell thickness, which decreased with increasing plantation age. Curvilinear correlations were established between kernel percentage and nut weight, kernel percentage and shell thickness, and kernel weight and internal septum weight. The greatest variability within a tree was found in nut and kernel weights, and the smallest in length of the nut.*

135. Newman, James A. 1972. WEED CONTROL IN WALNUT SEEDLINGS. *Univ. Ky. Dep. For. Res.* FOR-3, 2 p., illus.

*Discusses weed control in young black walnut plantings.*

136. Nikitinskii, Yu. I. 1970. [BIOLOGICAL AND ECOLOGICAL PRINCIPLES OF MANAGEMENT IN *JUGLANS REGIA* FORESTS.] *Izdatel'stvo Ilim, Frunze*, 210 p. [In Russian.]

*A monograph on the natural *J. regia* forests of Kirghizia, describing: environmental conditions, past history and present status, biological and ecological characteristics of *J. regia*, forest types, organization of seed production, plantations,*

falling in plantations and natural forests, etc. The monograph is a revised and enlarged version of a book already noticed.

137. Nikitinskii, Yu. I. 1970. [DICHOGAMY OF JUGLANS REGIA AND ITS PRACTICAL IMPORTANCE.] *In* The fruiting of *Juglans regia*, *Picea schrenkiana*, and *Juniperus* spp. in the Tien-Shan. Izdatel'stvo Ilim, Frunze, 137 p. [In Russian.]  
Not seen.
138. Nikitinskii, Yu. I. 1970. [GROWTH AND DEVELOPMENT OF PLANTATIONS OF JUGLANS REGIA UNDER CANOPY.] *In* Afforestation of non-irrigated and irrigated land in Kirghizia. Izdatel'stvo Ilim, Frunze, 79 p. [In Russian.]  
Not seen.
139. Nikitinskii, Yu. I. 1970. [INHERITANCE OF PROTEROGYNY AND PROTERANDRY IN JUGLANS REGIA.] *In* The fruiting of *Juglans regia*, *Picea schrenkiana*, and *Juniperus* spp. in the Tien-Shan. Izdatel'stvo Ilim, Frunze, 137 p. [In Russian.]  
Not seen.
140. Nikitinskii, Yu. I. 1970. [THE RELATION BETWEEN HEARTWOOD FORMATION AND DEFECTS IN JUGLANS REGIA.] *In* Afforestation of non-irrigated and irrigated land in Kirghizia. Izdatel'stvo Ilim, Frunze, 79 p. [In Russian.]  
Not seen.
141. Ogienko, A. P. 1971. [REPRODUCTION OF JUGLANS REGIA.] Lesn. Khoz. 10: 91-92. [In Russian.]  
Not seen.
142. Ohta, A. 1973. ISOLATION OF NAPHTHAZARIN FROM WALNUT 'ONIGURUMI' AND ITS INHIBITORY ACTION ON OXIDATIVE PHOSPHORYLATION IN MITOCHONDRIA (JUGLANS MANDSHURICA MAXIM). Toxicon 11(3): 235-241.  
*Investigations of lethal substances other than juglone in the walnut 'Onigurumi,' led to the isolation and identification for the first time, of 5,8-dihydroxy-1,4-naphthaquinone (naphthazarin) in plants. Naphthazarin had a complicated dualistic effect acting both as an uncoupler and an energy transfer inhibitor, while juglone was only an energy transfer inhibitor.*
143. Ölez, H. 1971. [AN IMPROVED METHOD FOR DETERMINING THE POTENTIAL YIELD OF WALNUT TREES.] Yalova Bahçe Kült. Araştırma Eğitim Merkezi Derg. 4(1/4): 20-30. [In Turkish with English summary.]  
*The forthcoming yield of 48 (*Juglans regia*?) trees of different ages was successfully calculated in two successive years from the percentages of terminal and lateral buds producing pistillate flowers and the available numbers of pistillate flowers per terminal and lateral bud.*
144. Ölez, H. 1971. [STUDIES ON THE SELECTION OF WALNUT, JUGLANS REGIA, IN THE MARMARA REGION.] Yalova Bahçe Kült. Araştırma Eğitim Merkezi Derg. 4(1/4): 7-20. [In Turkish with English summary.]  
*The selection of 20 walnut types from 323 promising trees is described, and data on the form and growth of the trees, yield potential, flowering habit (protrandous, etc.), and fruit characteristics are tabulated.*
145. Olisaev, V. A., and M. A. Tekoev. 1971. [ON RAISING PLANTING STOCK OF JUGLANS REGIA.] Lesn. Khoz. 10: 7-9. [In Russian.]  
Not seen.
146. Oprea, C. 1969. [A STUDY OF THE MORPHOLOGY OF THE WALNUT FRUIT.] Lucr. Stiint. Inst. Agron. "N. Bălcescu," B, 12: 321-333. [In Romanian with English summary.]  
*The structure of the fruit (*Juglans regia*?) is described and illustrated.*
147. Orlova, N. A. 1970. [FEATURES OF THE FLOWERING AND FRUITING OF JUGLANS SPP. IN N. KIRGHIZIA.] *In* The fruiting of *Juglans regia*, *Picea schrenkiana*, and *Juniperus* spp. in the Tien-Shan. Izdatel'stvo Ilim, Frunze, 137 p. [In Russian.]  
Not seen.
148. Parker, J. 1969. FURTHER STUDIES OF DROUGHT RESISTANCE IN WOODY PLANTS. Bot. Rev. 35: 317-371.  
*A review with 288 references. Soil moisture effects are briefly covered. *Juglans* and *Platanus* spp. are included.*
149. Parrot, Louis. 1969. [THE NEED FOR A TREE-BREEDING PROGRAM FOR CERTAIN HARDWOOD-FOREST SPECIES: APPLICATIONS IN THE GENERA JUGLANS AND ACER.] For. Chron. 45(6): 386-392. [In French with English summary.]  
*In a black walnut provenance-study plantation in Quebec, spring frost damage during the first 2 yr was strongly correlated with latitude of seed origin. No trees originating in Canada were damaged; frost injury to trees from U.S. collections ranged from 9 percent (Vermont) to 87 percent (Tennessee).*

150. Parrot, Louis. 1971. [CLIMATE, A SELECTION FACTOR IN THE GENETIC ADAPTATION OF *JUGLANS NIGRA*, AN EXOTIC SPECIES IN QUEBEC, CANADA.] *Silvae Genet.* 20(1-2): 1-9, illus. [In French with English summary.]

Field test of four provenances of black walnut was established during the years 1882-1884 at Pointe Platon, near Quebec, Canada. Following severe mortality at the seedling stage due to frost damage, the residual plantation, which was established on three river terraces, subsequently formed several well-defined populations as a result of genotype-environment interaction. These populations showed strong variation in degree of frost resistance. The best stems exhibit an increment and quality comparable with that for the species in the central United States.

151. Paul, Benson H. 1943. BLACK WALNUT FOR GUNSTOCKS. *South. Lumberman* 166(2089): 32-36.

Properties of open- and forest-grown black walnut from six States were related to growing conditions. Open-grown trees had heavier, harder wood and less variable moisture content than forest-grown trees. There were no differences in straightness of grain.

152. Petrosjan, A. A. 1970. [VARIATION IN WALNUTS PROPAGATED BY SEED.] *Sadovod. Mosk.* 10: 26-27. [In Russian.]

In trials with 30 forms of 5- to 9-yr-old trees of *Juglans regia* propagated from seed, variations were observed in type and time of flowering and of bearing, yields, time of fruit ripening, initiation and termination of seasonal growth, pest and disease resistance, winter hardiness, morphological characteristics of the tree, and commercial quality of the nuts.

153. Petrosjan, A. A., and G. A. Antonenko. 1972. [SECOND FLOWERING AND CROPPING IN WALNUT.] *Subtrop. Kul't.* 2: 112-118. [In Russian.]

Ten trees obtained from seedlings of different walnut varieties and capable of flowering and fruiting twice a year were studied for 6 years. The trees that started bearing in the third year flowered normally in late April and early May and again in late May and early June. The second inflorescences (35 to 50 cm long), produced on short green shoots of the current year's growth, consisted of staminate, pistillate, staminate and pistillate, or hermaphrodite flowers. The fruits from the second flowering ripened almost simultaneously with

those from the first but were slightly smaller. Each type of inflorescence is described and the economic possibilities of a wide distribution of this type of walnut tree are discussed.

154. Petukhova, I. P. 1971. [VARIATION IN 'CATALASE QUALITY' IN TWO SPECIES OF *JUGLANS*.] *Bjul. Gl. Bot. Sada* 79: 62-65. [In Russian.]

Seasonal variations in 'catalase quality' (number of active molecules per gram-mole of the enzyme) were determined in the leaf and bark of 2-yr seedlings of *J. mandshurica* and *J. regia* grown at Vladivostok and the more severe climate of Sverdlovsk. The results (shown in graphs) confirm that variations in catalase quality can serve as an indication of winter hardiness.

155. Petukhova, I. P. 1972. [GROWTH RHYTHM OF *JUGLANS MANDSHURICA* IN RELATION TO PLANT INTRODUCTION.] *In* *Rastenii Prirodnoi Fauny Sibiri Dlia Zelenogo Stroitel'stva*, p. 117-181. [In Russian.]

Not seen.

156. Phares, Robert E. 1965. MINERAL NUTRITION OF FOREST TREE SEEDLINGS. *Diss. Abst.* 25(9): 4930.

Includes results from a pot experiment with black walnut using forest and old-field soils collected in Iowa and Missouri. The walnut seedlings grew significantly better on the forest soils than on the old-field soils. Seedling growth on all of the soils, however, was improved by addition of fertilizers. Results of chemical analyses for 12 elements in the leaves of the walnut seedlings are also included in the report.

157. Phares, Robert E. 1973. MANAGING IMMATURE TREES FOR MORE HIGH-QUALITY LOGS AND RELATED PRODUCTS. *In* *Black walnut as a crop*. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 49-54, illus. North Cent. For. Exp. Stn., St. Paul, Minn.

A general review of some of the basic cultural practices in managing immature black walnut trees is presented. It is proposed that potential crop trees be selected as early in the rotation as possible and cultured on an individual tree basis. Early release and thinning are also recommended for maintaining rapid growth. Study results show that pole-sized and small sawtimber-sized walnut trees also grow faster if released and thinned, but older sawtimber-sized trees show little or no response. Tentative stocking and spacing levels for

maintaining good growth and good nut production are presented. Corrective pruning and clear-stem pruning are necessary at appropriate times during the rotation to produce straight stems and high-quality wood. Research in progress indicates that fertilization also may be feasible for maintaining good growth.

158. Phares, Robert E., and Raymond F. Finn. 1972. USING FOLIAGE ANALYSIS TO HELP DIAGNOSE NUTRIENT DEFICIENCIES IN BLACK WALNUT. North. Nut Grow. Assoc. Annu. Rep. 62(1971): 98-104, illus.

The presence or absence of nutrient deficiency symptoms can serve as a quick guide to the nutrient status of black walnut plantations or orchards. Deficiency symptoms for several essential nutrients are described and illustrated with color plates. Laboratory analyses should be made to verify suspected nutrient deficiencies. Tentative critical foliage nutrient levels are presented to aid in evaluating results of the laboratory analysis. Suggested procedures for collecting and processing leaf samples are also given.

159. Phares, Robert E., and Robert D. Williams. 1971. CROWN RELEASE PROMOTES FASTER DIAMETER GROWTH OF POLE-SIZE BLACK WALNUT. USDA For. Serv. Res. Note NC-124, 4 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Complete crown release more than doubled the diameter growth of pole-size black walnut trees in southern Indiana over a 10-yr period. Partially released trees grew about 50 percent more than unreleased trees. Most of the trees produced bole sprouts; however, the incidence of sprouting was higher and the sprouts were larger on the completely released trees than on the unreleased trees. Controlling understory growth had no significant effect on growth of the walnut trees.

160. Pieniazek, S. A. 1968. AUTUMN GRAFTING OF WALNUTS. Am. Nurseryman 128(1): 20.

In Poland, scions of black or English walnut are collected in early October, bench-grafted on dormant seedlings, and packed in a box maintained at 78 to 80° F for 3 weeks. Grafted plants can then be field-planted or put into cold storage until spring. Up to 90 percent success is claimed for the method.

161. Prutenskaja, M. D., and V. S. Ševčenko. 1970. [GRAFTING LARGE JUGLANS REGIA TREES.] Lesn. Khoz. 7: 35-36. [In Russian.]

Rind (crown) grafts were made on decapitated stems in 20-yr plantations in Kirghizia. Details of the technique and of subsequent graft survival are given. Although the grafting was done with great care, survival after 4 yr was <40 percent, and it is concluded that this method is unsuitable for large-scale improvement of nonvarietal plantations or natural forests of J. regia. Instead, such stands should be improved by removing inferior and unhealthy trees.

162. Prutenskaja, M. D., and V. S. Ševčenko. 1971. [THE HARMFULNESS OF A LEAF-BLOTCH DISEASE OF JUGLANS REGIA, AND MEASURES TO CONTROL IT IN S. KIRGHIZIA.] Mikol. i Fitopatol. 5(2): 172-175. [In Russian.]

Data are given showing the harmful effect of the disease [pathogen Gnomonia [leptostyla], conidial stage Marssonina juglandis] on shoot growth and fruit weight. Some interspecific hybrids of J. regia with J. nigra, J. cinerea, and J. sieboldiana have proved to be immune, as have forms of J. regia introduced into Kirghizia from other regions of the U.S.S.R.

163. Ramina, A. 1970. [STUDIES ON THE FLORAL BIOLOGY AND FRUITING OF WALNUT (JUGLANS REGIA). III. BIOMETRIC AND CHEMICAL DETERMINATIONS ON THE FRUIT DURING GROWTH.] Riv. Ortoflorofruttic. 54: 293-300. [In Italian with English summary.]

The growth in length and width of the fruit of Sorrento walnuts (J. regia) followed a double sigmoid curve; it was very rapid at first, slowed down for several weeks (phase II), increased again, and finally leveled off. In both years of the study, the start of phase II corresponded with the onset of hardening of the endocarp, which took about 25 days. Changes in the water, N, P, K, and Ca contents of the fruit during its growth are described.

164. Ramina, A. 1970. [RESEARCH ON FLORAL BIOLOGY AND FRUITING IN WALNUT (JUGLANS REGIA L.) IV. INFLUENCE OF LEAVES AND FRUITS ON FLOWER BUD INDUCTION.] Agric. Ital. 70(6): 383-397. [In Italian.]

Not seen.

165. Reitz, H. J., and W. C. Stiles. 1968. FERTILIZATION OF HIGH PRODUCING ORCHARDS. "CHANGING PATTERNS IN FERTILIZER USE." Soil Sci. Soc. Am. Symp. Proc., p. 353-378.

A summary review, with 13 references, of nutrient and fertilizer requirements of apple, citrus, and nuts.

166. Risser, Paul G., and Elroy L. Rice. 1971. PHYTOSOCIOLOGICAL ANALYSIS OF OKLAHOMA UPLAND FOREST SPECIES. Ecology 52(5): 940-945.  
*Black walnut is commonly associated with Cornus florida, Quercus alba, and Robinia pseudoacacia.*
167. Roth, Paul L. 1972. FIELD TRIALS OF SELECTED HERBICIDES IN A YOUNG TREE PLANTATION. North. Nut Grow. Assoc. Annu. Rep. 62(1971): 45-47.  
*On silt loam soils in southern Illinois, the best combination of weed control without injury to black walnut seedlings was provided by 6 lb simazine 80W plus 1/2 pt paraquat per acre applied before planting.*
168. Roth, Paul L., Calvin F. Bey, John R. Toliver, and Richard K. Kammler. 1972. BLACK WALNUT SEEDLINGS FROM SOUTH GROW FASTEST IN SOUTHERN ILLINOIS. Agric. at South., Spring Issue, p. 3.  
*Results from studying seven characters in black walnut trees originating in various geographic areas and planted at several locations are summarized. No geographic area produced unusually large or small black walnut seed. Trees originating in southern areas tend to flush earlier in the spring, hold their leaves longer in the fall, grow larger, and produce more lateral buds on the current year's terminal than trees originating in northern areas.*
169. Rudolph, V. J., W. A. Lemmien, and D. P. White. 1972. BLACK WALNUT STAND GROWTH IN SOUTHERN MICHIGAN. Mich. Agric. Exp. Stn. Res. Rep. 171, 11 p., illus.  
*The 10 black walnut plantations ranging in age from 19 to 56 yr, and the 60-yr-old natural stand for which data are presented in this report, show generally slow growth. These growth data also show that planting black walnut in mixtures with other species, or bordering walnut plantations with coniferous plantings, has little beneficial effect without additional cultural treatments.*
170. Ruts'kyi, I. A. 1971. [CYTOGENETIC AND MORPHOLOGICAL EFFECT OF GAMMA-RAY ACTION AND ETHYLENEIMINE ON SEEDS OF JUGLANS REGIA.] In Eksp. Mutatsii Sel. Rosl., p. 238-246.  
*Not seen.*
171. Šarova, N. I. 1970. [CONTENTS OF BIOLOGICALLY ACTIVE AND MINERAL SUBSTANCES IN WALNUTS.] Sb. Tr. Aspir. Molod. Nauchn. Sotr., Leningr. 15: 584-590. [In Russian.]  
*Immature walnut (Juglans regia?) fruits sampled on 20 June contained 2,186 to 3,069 mg percent ascorbic acid, the kernels a harvest on 5 September contained 13 to 6 mg percent. The kernels also contain 1 to 1.5 mg percent tocopherol; rutin was found in milky-ripe but not fully ripe. The Fe<sub>2</sub>O<sub>3</sub> content of the kernels ranged from 3.16 to 6.03 mg percent and MgO from 0.22 to 0.52 mg percent.*
172. Schaad, N. W. 1969. ANATOMICAL RELATIONS OF THE PATHOGEN ERWINIA RUBRIFACIENS TO THE TISSUES OF JUGLANS NIGRA L. Diss. Abstr. 30B(5): p. 1983.  
*Not seen.*
173. Schaad, N. W., M. G. Heskett, J. M. Gardner, and C. I. Kado. 1973. INFLUENCE OF INOCULUM DOSAGE, TIME AFTER WOUNDING, SEASON OF INFECTION OF PERSIAN WALNUT TREES BY ERWINIA RUBRIFACIENS. Phytopathology 63(3): 327-329.  
*Experimentally inflicted wounds of Persian walnuts (Juglans regia 'Hartley') are susceptible to infection by Erwinia rubrifaciens. Trees were not susceptible during the winter (January), but were highly susceptible in spring (April), summer (July), and fall (October). Wounds decreased in susceptibility with time at the average rate of 10 to 12 percent/day. Seven days after wounding fewer than 3 percent of wounds remained susceptible in April and October, and about 15 percent in July.*
174. Schaad, N. W., and E. E. Wilson. 1971. BACTERIAL PHLOEM CANCER OF PERSIAN WALNUT. Calif. Agric. 25(4): 4-7.  
*Describes the distribution in California, symptoms, spread, temperature requirements, etc., of this disease of cultivars of Juglans regia caused by Erwinia rubrifaciens. Attacks are largely confined to the Hartley cultivars. Natural infection has not been found in J. hindsii or J. californica. Control measures are described.*
175. Schaad, N. W., and E. E. Wilson. 1971. ECOLOGY OF ERWINIA RUBRIFACIENS AND DEVELOPMENT OF PHLOEM CANCER OF PERSIAN WALNUT (JUGLANS REGIA). Appl. Biol. Ann. 69(2): 125-136.  
*A requisite for development of bacterial phloem cancer is the presence of the highly susceptible Hartley cultivar. The age of the plant part is important in the disease which occurs only on trunks and primary (scaffold) branches. Extension of the cankers was most rapid during the summer when the temperature was high. Breaks in the*

thick phelloderm of the trunks and branches are necessary for penetration of the pathogen to the inner bark. Of the several types of breaks commonly occurring, those produced by mechanical harvesting equipment and by sap-sucking birds were found to be infection sites.

176. Schumann, David R. 1971. DIMENSION YIELDS FROM BLACK WALNUT LUMBER. USDA For. Serv. Res. Pap. FPL-162, 17 p. For. Prod. Lab., Madison, Wis.

Yield of dimension from top grades of walnut lumber can be predicted by charts. Various grades can be compared to determine the most economical mix for a specific cutting order.

177. Schumann, David R. 1973. DIMENSION STOCK YIELDS FROM LUMBER OF THREE HARDWOOD SPECIES. For. Prod. J. 23(3): 17-21.

The significance of recent dimension stock yield studies using hard maple, black walnut, and red alder, is discussed in light of its interest to manufacturers, consumers, and scientists. The data are useful in determining the most economical lumber grade(s) for specific requirements, facilitating more complete utilization of the resource by demonstrating maximum obtainable yield, and encouraging the use of the lower grades that are in greatest supply. The application of the data by use of a nomograph is illustrated, and the acceptance of the data and its relationship to associated research is summarized.

178. Schumann, David R. 1973. MECHANICAL, PHYSICAL, AND MACHINING PROPERTIES OF BLACK WALNUT FROM INDIANA AND MISSOURI. Wood & Fiber 5(1): 14-20.

Machining properties of black walnut were satisfactory regardless of locality, site, growth rate, and anatomical characteristics. Specific gravity influenced the machining and mechanical properties more than any other feature. Indiana-grown black walnut heartwood contained less extractive material and consequently shrank more than Missouri-grown wood. Good sites, regardless of location, produced tougher wood than poor sites.

179. Sdrawkow, K. 1973. [PRESENT SITUATION AND PROBLEMS CONCERNING CULTIVATION AND MANAGEMENT OF WALNUT TREES IN PEOPLE'S REPUBLIC OF BULGARIA.] Soz. Forstwirtschaft. 23(5): 152-153. [In German.]

Not seen.

180. Serr, E. F. 1960. WALNUT ORCHARDS ON VOLCANIC SOILS DEFICIENT IN PHOSPHORUS. Calif. Agric. 14(6): 6-7.

Triple super placed in trenches 6 in. deep and 2 ft from the trunks of young trees and 5 ft from the trunks of mature trees significantly increased yields. Broadcasting fertilizer was not effective.

181. Sester, John A. 1973. FOREST PRODUCTS REGULATORY LEGISLATION. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 26-27. North Cent. For. Exp. Stn., St. Paul, Minn.

The intent of the Illinois Timber Buyers Licensing Act is to protect the landowner's right to receive monies due for timber sold, and to protect against timber piracy. The law requires anyone buying timber from the timber owner to be licensed. To obtain a license a surety bond must be posted. Amount of bonding surety is based on total timber purchases. Anyone transporting two or more logs or Christmas trees on any road in Illinois may be required to show proof of ownership under provisions of the Forest Products Transportation Act.

182. Shchepot'ev, F. L., and A. G. Gerasimenko. 1970. [ON APOMIXIS IN PERSIAN WALNUT.] In Apomiksis i Sel. p. 232-238. [In Russian.] Not seen.

183. Shchepot'ev, F. L., and A. E. Kenig. 1971. [NUT TREE CULTURE (JUGLANS) IN UKRAINE.] Lesovod. Agrolesomeliior. 25: 39-46. [In Russian.] Not seen.

184. Shreve, Loy W. 1973. PROPAGATION OF WALNUT, CHESTNUT, AND PECAN BY ROOTED CUTTINGS. Eighth Cent. States For. Tree Improv. Conf., Columbia, Mo. 10 p.

Softwood cuttings from adventitious shoots and current-year seedlings of black walnuts were rooted under intermittent mist when treated with IBA in 95 percent ethanol. Rooting percentages of 80 to 100 were attained from shoots of adventitious origin with 1-, 3-, and 4-yr-old seedlings, and lower limbs of a 13-yr-old tree. Rooting percentages of cuttings made from current-year seedlings were similarly high. Seventy-three percent of rooted cuttings transplanted from the mist bed to containers in the greenhouse initiated shoot growth within 2 to 6 weeks after being transplanted.

185. Shreve, Loy W., and Neil W. Miles. 1972. PROPAGATING BLACK WALNUT CLONES FROM ROOTED CUTTINGS. *Plant Propag.* 18(3): 4-7.  
*Softwood cuttings from shoots originating from adventitious buds of black walnut were successfully rooted under intermittent mist when selected at the right stage of development and treated with 5,000, 8,000, or 10,000 p/m IBA in 95 percent ethanol. Rooting percents of 80 to 100 were attained using cuttings taken from shoots of adventitious origin from 1-, 3-, and 4-yr-old seedlings, a 135-yr-old stump, and lower limbs of a 13-yr-old tree. Rooting percents of cuttings made from terminals of current-year seedlings were similarly high. Seventy-three percent of rooted cuttings transplanted from the mist bed to containers in the greenhouse survived and initiated new growth.*
186. Shuhart, D. V. 1932. INNER SCULPTURING OF THE FRUIT OF JUGLANDACEAE. *Okla. Acad. Sci. Proc.* 12: 17-18.  
*The original carpellary cavities are narrow slits with smooth walls. The carpellary tissue gives rise to a continuous endocarp, a more or less inconspicuous mesocarp, and parenchymatous endocarp. The exocarp develops into the hard outer shell of the nut.*
187. Shvidenko, A. I. 1970. [INJURIES CAUSED TO WALNUT TREES BY FROSTS IN BUKOVINA.] *Lesovedenie* 1: 89-90. [In Russian.]  
*Not seen.*
188. Shvidenko, A. I. 1971. [GROWTH OF JUGLANS REGIA WITH OAK ON DRY OAK FOREST SITES.] *Lesn. Khoz.* 10: 10-12. [In Russian.]  
*Describes studies in mixed walnut/oak plantations in the forest-steppe region of the West Ukraine. The walnut, which has been deliberately favored by various silvicultural measures, has a greater height and diameter than oak at age 10 yr, but the oak eventually suppresses it, and these species should be regarded as incompatible for mixed plantations.*
189. Simovski, K. 1972. [TIME OF WALNUT GRAFTING IN REGIONS OF SKOPJE (MACEDONIA).] *Jugosl. Vocarstvo* 6(10/20): 699-704. [In Croatian with English summary.]  
*Not seen.*
190. Sladký, Z. 1972. THE ROLE OF ENDOGENOUS GROWTH REGULATORS IN THE DIFFERENTIATION PROCESSES OF WALNUT (JUGLANS REGIA L.). *Biol. Plant.* 14(4): 273-278.  
*Further bioassays of auxins and gibberellin-like substances were made on developing young fruits, and mature leaves of a tree aged 40 yr, after separation by paper chromatography. Complex patterns of different growth regulators and inhibitors were revealed, and their significance is discussed. The development of bud primordia in the second year after spraying the young leaves with active substances showed that: IAA or MH (maleic hydrazide) made male flowers revert to vegetative buds that developed abnormal leaves resembling those of the more primitive family Fagaceae; triiodobenzoic acid transformed vegetative buds in the male catkins; male catkins formed some female flowers after higher doses of IAA and female flowers were not affected by treatment (presumably owing to high concentrations of endogenous substances), but fruit development was distorted.*
191. Smagin, N. E. 1970. [FROST RESISTANCE FORMS OF WALNUT.] *Sadovodstvo* 11: 31. [In Russian.]  
*Of 2,500 walnut (Juglans regia?) trees studied in 1968-1969, 40 were only slightly damaged at -30° C, and 12 of these that showed good commercial qualities were selected.*
192. Smith, Christopher C., and David Follmer. 1972. FOOD PREFERENCES OF SQUIRRELS. *Ecology* 53(1): 82-91.  
*Both fox and gray squirrels prefer shagbark black walnut kernels over shagbark hickory or any of four species of oak kernels. A proximately 15 min was required to open and eat a fresh whole walnut. Coevolution of squirrels and most species is discussed.*
193. Smith, H. H., and O. W. Torgeson. 1955. KILN SCHEDULE FOR BLACK WALNUT GUNSTOCK BLANKS. *USDA For. Serv. Rep. FPL-R1433.* For. Prod. Lab., Madison, Wis.  
*A proposed commercial kiln schedule, faster and hotter than previously published schedules, is limited by prohibitive degradation as higher temperatures are reached. A top temperature of 165° F is recommended.*
194. Smith, Richard C. 1973. RETURNS FROM TWO SYSTEMS OF MULTICROPPING. In *Black walnut as a crop. Black Walnut Symp.*, Carbondale, Ill., Aug. 14-15, 1973. *USDA For. Serv. Gen. Tech. Rep. NC-4*, p. 106-110. North Cent. For. Exp. Stn., St. Paul, Minn.  
*An analysis was made of costs and returns from two hypothetical black walnut plantations of different spacings in which fescue was grown for seed between the rows of trees.*

- and nuts were sold. Fescue seed and nuts contributed a substantial share to total revenue. After allowance for all costs including income taxes, the internal rates of return were 8.3 and 12.9 percent respectively for the 18- by 18- and 40- by 40-ft spacings. Benefit-cost ratios were 1.39 and 1.67, based on a 6 percent discount rate. With the cost of land and initial costs of establishment assumed, \$15,000 to \$16,000 would be required to start a 40-acre plantation.
195. Stebbins, Robert L. 1973. USE OF LEAF ANALYSIS FOR WALNUTS AND FILBERTS. *Nut Grow. Soc. Oreg. Wash. Proc.* 58: 37-42.  
Summarizes trends in number of leaf samples sent in by walnut (probably *Juglans regia*) and filbert growers in Oregon that show deficiencies of nitrogen, potassium, and boron. Deficiency levels for each of these mineral nutrients are also given for both tree species. The levels of nitrogen in samples sent in by growers in recent years have been declining, probably because more ammonium-type fertilizers are being used and there is less nitrification with acidification of the soils.
196. Stone, Donald E. 1970. EVOLUTION OF COTYLEDONARY AND NODAL VASCULATURE IN THE JUGLANDACEAE. *Am. J. Bot.* 57(10): 1219-1225.  
Increased nodal complexity in the Juglandaceae is associated with at least two independent evolutionary shifts from epigeal to hypogeal germination. Presumably the complex development of the cotyledonary node is a response to increased functional demands of hypogeous cotyledons.
197. Sushko, M. T. 1970. [POLYMORPHISM OF *JUGLANS REGIA* L. IN THE PAMIRO-ALAI MOUNTAIN COUNTRY AND IN THE PAMIRS.] *Rastit. Resur.* 6(3): 383-390. [In Russian.]  
The great diversity of *Juglans regia* types found in these regions is of interest for both commercial use and breeding.
198. Sushko, M. T. 1973. [DETAILS, ORIGIN AND STRUCTURE OF BURLS IN *JUGLANS REGIA*.] *Rastit. Resur.* 9(1): 118-123. [In Russian.]  
Not seen.
199. Sushko, M. T. 1973. [*JUGLANS MANSHURICA* AND ITS SUPPLY IN SOVIET FAR EAST.] *Rastit. Resur.* 9(2): 271-279. [In Russian.]  
Not seen.
200. Szopa, P. S., D. E. Hartley, and A. E. McGinnes. 1973. HARDWOOD BARK-AMENDED SOIL AS A POTTING MEDIUM FOR CONTAINER-GROWN CHRYSANTHEMUMS. *For. Prod. J.* 23(1): 43-46.  
Hammermilled bark from seven hardwood species was studied as a possible alternate for peat moss in the production of potted chrysanthemum plants. In general, plants grown in bark-amended mixes were less succulent (more "woody") and had fewer flowers. The pH of bark-amended soils was higher than peat-amended soils, often above pH 7.0 and approaching undesirable levels for optimum nutrient uptake. Walnut, maple, and sycamore bark yielded more satisfactory plants than oak or ash bark.
201. Tastvoreva, O. G. 1966. [THE MOISTURE REGIME OF SOILS UNDER STANDS OF SOME TREE SPECIES ON FOREST STEPPE.] *Vestn. Leningr. Inst.* 15: 135-146. [In Russian.]  
Moisture regime was studied under pure stands, 25 yr old, density 1.0, height 8 to 11 m, of petiolate oak, Siberian larch, Amur cork tree, and Manchurian walnut. Mean rainfall was 390 to 620 mm, soil clay content 20 to 30 percent, porosity 48 percent. Penetration of moisture was greatest under cork and walnut; most of the moisture coming from thawed snow. The lowest moisture supply was found under larch; the highest under walnut and cork. Under walnut and cork a soil layer with high moisture content (16 to 20 percent) was found at 2 to 4 m depth.
202. Taverna, G. 1968. [THE ACTIVITY OF 5-OXY-NAPHTHOQUINONE IN THE METABOLISM OF THE JUGLANDACEAE. III.] *Fac. Sci. Agrar. Napoli Ann.* 3: 292-298. [In Italian with English summary.]  
Juglone was detected in all the green parts of a *J. regia* tree; i.e., in the inflorescence, stem cortex, leaves, and fruit husk. The total content of juglone in the husk generally increased between 6 May and 26 September although on dry and fresh weight bases the content decreased; the amount present depended on the size of the fruit and not on the date. Shading the fruit with black paper and defoliating the fruiting branch slightly delayed fruit growth but completely prevented the accumulation of juglone in the husk. This finding and the fact that leaves of fruiting branches were the richest in juglone support the idea that the juglone of the fruit is elaborated partly in the husk and partly in the adjacent leaves, and that the synthetic process is light dependent.

203. Tsurkan, I. P., and E. I. Chebotar'. 1972. [WHIP-GRAFTING WALNUTS.] Sadovostvo 10: 30-31. [In Russian.]  
Walnut seedling rootstocks with a stem diameter of 1.2 to 1.5 cm were lifted in late autumn and heeled in. Scion cuttings were taken from the mother tree shortly before grafting. The rootstocks and scions were kept in moist sawdust at 26 to 28° C for 10 to 15 and 2 to 3 days, respectively. After bench grafting at monthly intervals from December to April, the grafts were stratified in fungicide-treated moist sawdust in boxes at 26 to 28° C. Callusing occurred in 10 to 15 days. Maximum and minimum callusing occurred in plants grafted in December and in March to April, respectively. The callused material stored satisfactorily at 0 to +2° C until planting in early May. Outplanting and aftercare are described.
204. Tucović, A., L. Marković, and V. Valčić. 1972. [PRELIMINARY RESULTS OF EARLY PROVENANCE TESTS OF WALNUT (*JUGLANS REGIA* L.) IN YUGOSLAVIA.] Acta Biol. Jugosl. Ser. F Genet. 4(2): 229-244. [In Croatian with English summary.]  
Trees from 14 locations in 4 different climatic regions in Yugoslavia were established in 2 nurseries. The largest trees originated in the Ba-Ljig region. The proportion of monoaxial plants varied in accordance with the geographical latitude and height above sea level.
205. Uriu, K., and D. H. Chaney. 1970. FOLIAR SPRAYS FOR CORRECTING ZINC DEFICIENCIES IN WALNUTS. Calif. Agric. 24(3): 10-11.  
Treatments to trees with Zn deficiency symptoms were: (1)  $ZnSO_4$  applied in 1966, (2)  $ZnSO_4$  + hydrated lime applied once in 1966 and once in 1968, (3)  $ZnSO_4$  + hydrated lime twice in 1966 and twice in 1968, and (4) Zn EDTS four times in 1966 and twice in 1968. Deficiency correction was best with (4) and nearly as good with (3).
206. Veihmeyer, F. J. 1972. THE AVAILABILITY OF SOIL MOISTURE TO PLANTS: RESULTS OF EMPIRICAL EXPERIMENTS WITH FRUIT TREES. Soil Sci. 114(4): 268-294, illus.  
Portions of this article describe a 24-yr study to determine the effect of five moisture regimes on the growth of Concord walnuts with northern black walnut rootstock. Moisture regimes ranged from no irrigation (soil allowed to dry out) to frequent irrigation (soil at or above field capacity).  
There was no significant treatment response on yield of walnuts, growth and size of walnuts, or growth of the trees. Lack of treatment response was attributed to large amounts of soil moisture in the upper 60 cm of soil that was not depleted before most of the annual growth had been completed.
207. Vernik, R. S. 1961. [ECOLOGICAL CONDITIONS OF GROWTH OF WALNUT-FRUIT-TREE FORESTS IN THE BOSTANDYK REGION OF UZBEKISTAN.] Bot. Zh. 45: 1766-1773. [In Russian.]  
Even on southern slopes of the Ugam mountain range the soil-moisture content at the driest time of the year was greater than the wilting coefficient of walnut on broad forest soil when the soil was deep. On southern slopes that were bare or were eroded and planted with almond, soil moisture was insufficient.
208. Vernik, R. S. 1970. [EXPENDITURE OF WATER IN TRANSPIRATION BY WALNUT FOREST IN THE UPPER REACHES OF THE CHIRCHIK VALLEY.] Lesovedenie 5: 21-26. [In Russian with English summary.]  
Tabulates details of the transpiration of *Juglans regia*, *Prunus sogdiana*, *Crataegus turkestanica*, and the herb layer in several different walnut forest types in the West Tien Shan Mountains. Water expenditure in transpiration is compared with mensuration data for the stands, and conclusions are drawn on the optimum stand composition and constitution as regards forest productivity.
209. Vinogradov, N. P. 1970. [THE (NUT) YIELD OF THE WALNUT STANDS OF S. KIRGHIZIA.] In The fruiting of *Juglans regia*, *Picea schrenkiana*, and *Juniperus* spp. in the Tien-Shan. Izdatel'stvo Ilim., Frunze, 137 p. [In Russian.]  
Not seen.
210. Vinogradov, N. P., and V. A. Vinogradov. 1971. [BREEDING AND REPRODUCTION OF *JUGLANS REGIA* IN SOUTHERN KIRGHIZIA.] Lesn. Khoz. 10: 83-85. [In Russian.]  
Not seen.
211. Vishanska, Yu. V., and S. Ivanov. 1971. FATTY ACID COMPOSITION OF THE OILS OF SOME LOCAL WALNUT VARIETIES. C. R. Acad. Agr. Georgi Dimitrov 5(3): 213-215.  
Kernel oil content and fatty acid composition of the oil, including the ratios of linoleic:linolenic acids, were studied in five Bulgarian varieties.

212. Vonica, I. 1972. [THE WALNUT-TREE ANTHRACNOSIS CAUSED BY GNOMONIA LEPTOSTYLA (FR.) CES. ET DE NOT. AND THE WAY OF CONTROLLING IT.] Rev. Hortic. Vitic. 20(5): 82-86. [In Romanian with English summary.]  
The biological cycle of the pathogenic agent was studied and it was found that the transmission of the disease from year to year is performed only through the intermediary of the perfect form and that many conidia producing secondary infections develop on the organs attacked, during the vegetation period. As a function of the fungus biology, the walnut phenology and the climatic conditions, three to six treatments are required, in most years the first treatment being applied during ament formation, for blocking the first primary infections. Most effective were the copper-based products and the organically synthesized ones.
213. Vrcelj-Kitic, Darinka. 1968. [BLACK WALNUT (JUGLANS NIGRA L.) IN SERBIA.] Zbornik 8: 63-86, illus. [In Serbian with English summary.]  
Ecological conditions and development of black walnut in four plantations in Yugoslavia are described. A 54-yr-old plantation on dunes of deep sandy loam averages 20.5 m tall. On very deep chernozem soils, three plantations 32 to 35 yr old range from 19.8 to 22.0 m tall.
214. Wahlgren, H. E. 1973. EVALUATION OF SELECTED WOOD PROPERTIES IN RELATION TO SOIL-SITE CONDITIONS. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 17-22. North Cent. For. Exp. Stn., St. Paul, Minn.  
Relationships in black walnut wood color, specific gravity, extractive content, anatomical characteristics, machining, and mechanical properties were explored. The influence of geographic location, site quality, and growth conditions on these properties was also examined. Luminance was related to extractive content and to the combination of extractive content and some measures of wood density. Indiana trees differed significantly from Missouri trees by having: higher luminance value, lower extractive content, greater shrinkage, higher proportion of fibrous tissue with thinner cell walls, and smaller vessel lumens. No differences were detected in the physical characteristics or properties between trees from the two States.
215. Weeks, Jack. 1973. BLUEGRASS SOD AND TREES. In Black walnut as a crop. Black Walnut Symp., Carbondale, Ill., Aug. 14-15, 1973. USDA For. Serv. Gen. Tech. Rep. NC-4, p. 84-85. North Cent. For. Exp. Stn., St. Paul, Minn.  
Profit was the motive when 80 acres of black walnuts were planted 11 yr ago. Since then I have learned a great deal about walnuts and as yet have received no profit; however, I harvested 8,600 pounds of fine-quality nuts last year. I expect to start making a small profit in the next 2 or 3 yr. Using bluegrass as a second crop in the orchard has brought a reasonable return on the land while the trees grow into bearing and will play a great part in the future profits from this operation.
216. Wichman, J. R., and W. R. Byrnes. 1971. INHERENT TOLERANCE OF BLACK WALNUT AND TULIP POPLAR SEEDLINGS TO SOIL-APPLIED HERBICIDES. Purdue Univ. Agric. Exp. Stn. Res. Bull. 878, 6 p.  
Black walnut and tulip poplar seedlings were evaluated for their tolerance to simazine, atrazine, and diuron. One- and 2-yr-old nursery-grown seedlings as well as newly germinated seedlings grown in a sand or sand-vermiculite medium were treated with the herbicides in a greenhouse environment. Two-yr-old tulip poplar was tolerant to simazine at 0.25 p/m, but showed little or no tolerance to higher concentrations. Little tolerance was observed for tulip poplar to atrazine and diuron. In contrast, 1-yr-old black walnut was tolerant to 0.25, 0.50, and 1.00 p/m levels of simazine and to 0.25 p/m concentrations of atrazine and diuron. The response of newly germinated tulip poplar to simazine closely paralleled barley, a simazine-sensitive species; whereas the response of black walnut paralleled that of corn, a simazine-tolerant species. Chromatograms of foliar extracts indicated that black walnut was able to degrade simazine to at least four unidentified metabolites.
217. Williams, Robert D. 1971. THE EFFECT OF SEASON OF SOWING, STORAGE TREATMENT, AND HULLING ON GERMINATION AND GROWTH OF BLACK WALNUT SEED. Tree Plant. Notes 22(3): 21-22.  
The experiments reported showed that autumn-sown *Juglans nigra* seed produced more and larger seedlings than spring-sown at most Central States nurseries. Removing the husks of the nuts did not affect seedling yield, but reduced the volume of seed

by about two-thirds, making the seed easier to store and stratify.

218. Williams, Robert D. 1972. ROOT FIBROSITY PROVES INSIGNIFICANT IN SURVIVAL, GROWTH OF BLACK WALNUT SEEDLINGS. *Tree Plant. Notes* 23(3): 22-25, illus.

*In test plantings with black walnut in Illinois and Indiana, fibrous rooted seedlings did not survive better or grow faster than single taprooted seedlings. Stem diameter appears a better indicator of early height growth than root fibrosity.*

219. Williams, Robert D. 1972. STORING BLACK WALNUT SEED. *North. Nut Grow. Assoc. Annu. Rep.* 62(1971): 87-89, illus.

*Several tests were made to develop effective storage methods for black walnut seed using seed collected in southern Indiana in 1965, 1967, and 1968. Major variables included storage facility, seed moisture content, storage temperature, and length of time in storage. The seed retained its viability better in outside pits than in cold rooms. With pit storage, seed viability could be maintained up to 2 yr in storage with little loss in germination. Seed moisture content was not as critical for pit storage as for coldroom storage. For storage at 37° F the best seed moisture content was 40 percent; at 19° F it was between 20 and 30 percent; and at -15° F it had to be reduced below 20 percent to maintain germination.*

220. Williams, Robert D., David T. Funk, Robert E. Phares, Walter Lemmien, and Thomas E. Russell. APPARENT FREEZE DAMAGE OF BLACK WALNUT SEEDLINGS RELATED TO SEED SOURCE AND FERTILIZER TREATMENT. *Tree Plant. Notes*. (In press.)

*Following exposure to 15° F temperature in early November 1971 in a southern Indiana nursery, many walnut seedlings were top-killed. Trees of Kentucky, Tennessee, and*

*Alabama origin suffered about four times as much damage as those from Michigan. Seedlings fertilized with ammonium-type fertilizers were less severely affected than unfertilized seedlings or those treated with sodium nitrate. More than 60 percent of the injured seedlings died during the first growing season after outplanting.*

221. Williams, Robert D., and Robert E. Phares. 1973. BLACK WALNUT SEEDLING PRODUCTION RELATED NURSERY RESEARCH. *Northeast. Am. Nurserymen's Conf. Proc.*, p. 15-22, illus.

*A survey of 25 States growing black walnut planting stock shows that the demand for black walnut seed and seedlings increased throughout the 1960's. Seedlings shipped from the nurseries increased from about 729,000 in 1963 to more than 2.7 million in 1971. Annual shipments of seed and seedlings fluctuated greatly, primarily because of irregular seed supplies, root rot, and poor seed germination. Research related to these problems and to fertilization and weed control in black walnut seedbeds is discussed.*

222. Wilson, E. E., M. P. Starr, and J. A. Berger. 1957. BARK CANKER, A BACTERIAL DISEASE OF THE PERSIAN WALNUT TREE. *Phytopathology* 47: 669-673, illus.

*The disease is characterized by extensive, shallow, irregularly shaped cankers in the bark of the trunk and scaffold branches of mature trees. Cankers expand throughout the summer but are inactive in winter.*

223. Wright, Ernest, and H. R. Wells. 1948. TESTS ON THE ADAPTABILITY OF TREES AND SHRUBS TO SHELTERBELT PLANTING ON CERTAIN PHYMATOTRICHUM ROOT ROT INFESTED SOILS OF OKLAHOMA AND TEXAS. *J. For.* 46: 256-262, illus.

*Juglans nigra is of intermediate susceptibility and is tentatively recommended for shelterbelts on sandy sites.*

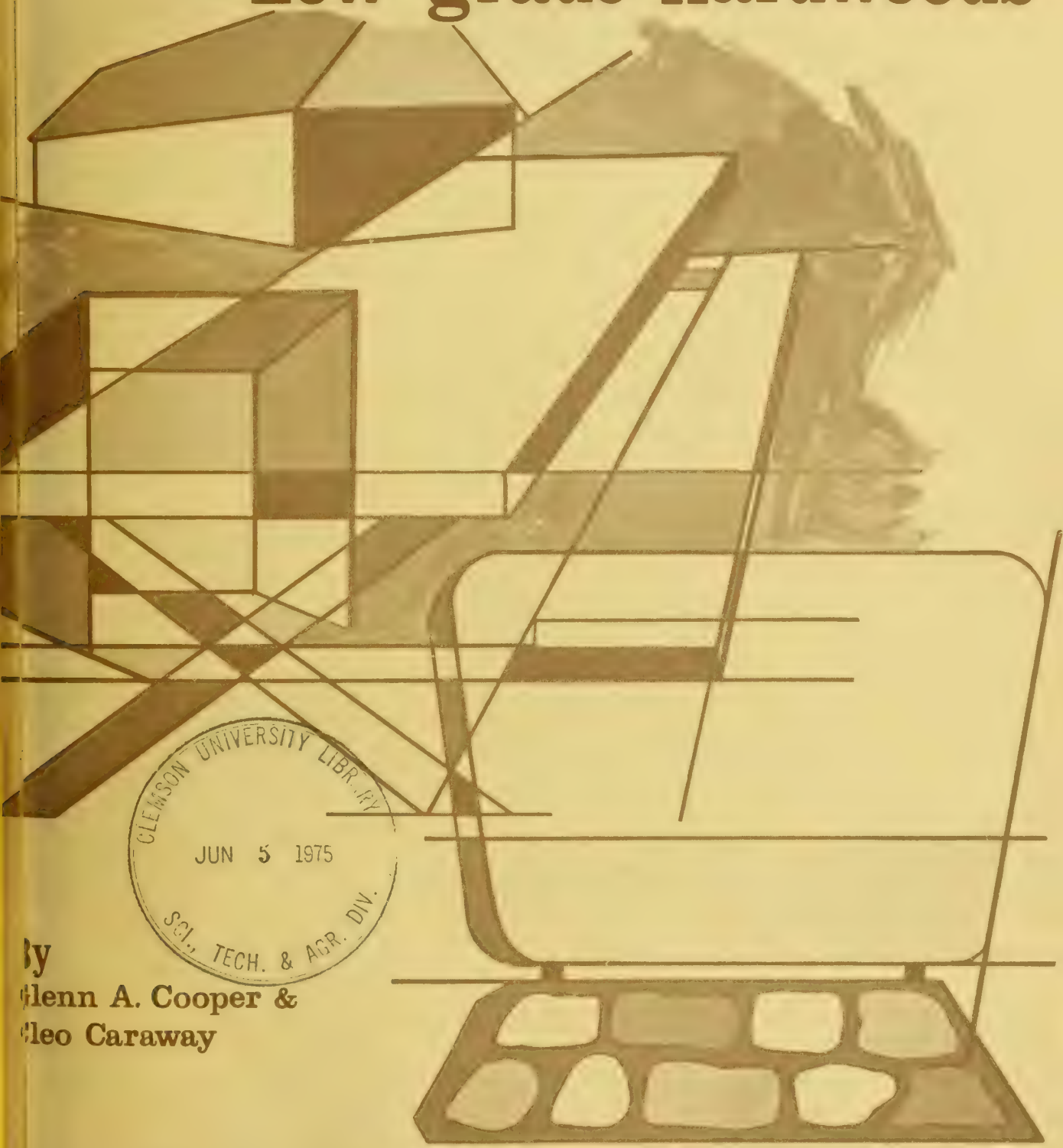




*Nature is beautiful...leave only your footprints.*

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# Build Recreation Structures From Low-grade Hardwoods



By  
**Glenn A. Cooper &  
Cleo Caraway**

NORTH CENTRAL FOREST EXPERIMENT STATION  
FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

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## FOREWORD

From 1957 to 1966 wood technologists at the Forestry Sciences Laboratory tested the use of low-grade hardwood lumber for various products. One such group of products was recreation structures. These experiments showed that hardwoods had advantages over the traditional softwoods.

The many publications on recreation structures that were developed are now out of print, but public demand for the information has continued. To meet that demand, we have assembled all our information on hardwood recreation structures into a single paper. Plans, costs, and production data useful to small and large producers of recreation products are taken from earlier publications. All costs have been updated to 1974.

All the original works are cited. For those who want more detail, the original papers may be available in forestry school libraries and large libraries that serve as depositories for government publications. They are *not* available in their original form from any USDA Forest Service office.

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## BUILD RECREATION STRUCTURES FROM LOW-GRADE HARDWOODS

Glenn A. Cooper and Cleo Caraway

A variety of outdoor recreation structures, such as tables, benches, seats, cabins, shelters, and signs, can be made from No. 2 and No. 3 Common hardwood lumber. A large volume of material is available for these products. In the hardwood forests of the eastern United States about two-thirds of the sawtimber volume is in logs of the lowest grade; only about 13 percent is in top-grade logs. More than two-thirds of the lumber sawn from low-grade logs is No. 2 Common or poorer grade, and even the best grades of logs yield as much as 25 percent of their volume in these grades of lumber. This material is usually less expensive than Construction grade softwoods. Many products, traditionally made from Western softwoods or only high-grade clear wood, can be made as well or better and more economically from the No. 2 and No. 3 Common grades of hardwood lumber.

Some common misconceptions about hardwoods have limited their utilization. One fallacy is that hardwoods cannot be nailed. True, hardwoods resist nail penetration more than softer woods; however, in industry today human effort is minimized by portable, pneumatic nailers and staplers. Furthermore, many hardwoods can be successfully hand-nailed if the proper nails are used. Then too, many recreation structures should not be nailed: lag bolts, screws, and carriage bolts are much more appropriate.

Another fallacy is that hardwoods are not suitable for construction. This probably arises more from our common acceptance and the wide availability of softwoods for construction than from anything else. Hardwoods have been used successfully for framing, siding, and trusses--uses commonly filled by softwoods. Properly selected hardwoods are, in fact, usually stronger than the softwoods.

A third fallacy is that hardwoods do not dry well. Many hardwoods do take longer to dry than most softwoods, but modern kiln schedules permit hardwoods to be dried successfully. Furthermore, in many recreation structures, air seasoning is all that is necessary to bring the wood to the optimum

moisture content, and minor seasoning defects are permissible in many products.

Hardwoods that are harder, heavier, and stronger than softwoods can be utilized to advantage in properly engineered products. The plans, designs, and production costs presented here were developed to put hardwoods to work advantageously. Everyone who wishes may utilize this information freely. It is presented in the hope that more products will be produced from the low-grade hardwoods and the pressure on higher priced grades and species of lumber will thereby be diminished.

### PRODUCTS FOR RECREATION AREAS

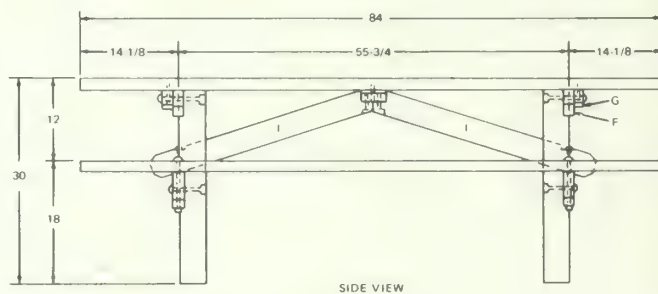
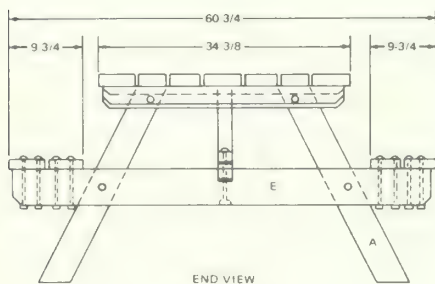
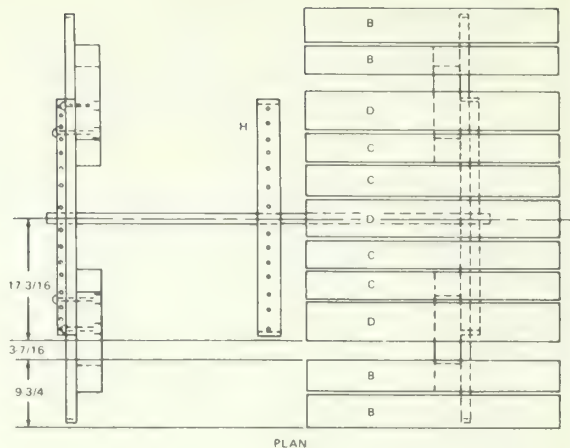
#### Hardwood Picnic Tables (Cooper 1963a)

Standard National Forest picnic tables can be built from red oak and hickory lumber using conventional woodworking shop methods and equipment (see Appendix). No. 2 Common and No. 3A Common lumber of both species give satisfactory yields. An acceptable table containing minor wood defects that do not detract from utility or appearance can be built for about \$53, plus indirect labor, machine, and overhead charges (figs. 1 and 2). Complete production data on labor time and materials costs for tables made of each grade and species follow.



Figure 1.--This 9-year-old, heavily used red oak table made from No. 3A Common lumber has been properly maintained and is in excellent condition.

MATERIAL LIST				
No.	Size	Fin.	Name and use	Mark
4	2"x4"x2'9 1/2"	S4S	Legs	A
4	2"x5"x2'	S4S	Seat planks	B
4	2"x4"x2'	S4S	Top planks	C
3	2"x6"x2'	S4S	Top planks	D
2	2"x6"x5'	S4S	Seat cleats	E
2	2"x4"x2'9 1/2"	S4S	Top leg brace	F
2	2"x3"x2'9 1/2"	S4S	Top cleat	G
1	2"x4"x2'9 1/2"	S4S	Top center cleat	H
1	2"x4"x2'9 1/2"	S4S	Braces	I
2	3/8"x9"	Galv.	Carriage bolts-brace	
16	3/8"x2 1/2"	Galv.	Carriage bolts-seat	
4	1/2"x6"	Galv.	Carriage bolts-top to legs	
4	1/2"x4 1/2"	Galv.	Carriage bolts-E to A	
50	3/8"x3"	Galv.	Lag screws-G, H to C, D	
68	3/8"x1"	Galv.	Washers-lag screws	
8	1/2"x1 1/2"	Galv.	Washers-bolts	



#### SPECIFICATIONS

Use most economical, durable species available (see Wood Handbook, (USDA Handbook 72), preferably heartwood cuts. Lumber shall be equivalent to West Coast Lumberman's Association "Construction" grade for Douglas fir. Lumber shall have an average moisture content, prior to treatment, of less than 20 percent.

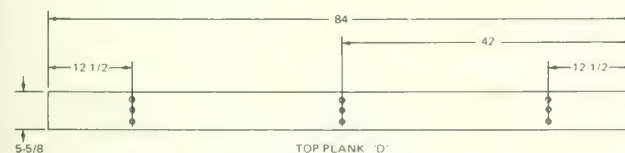
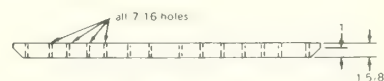
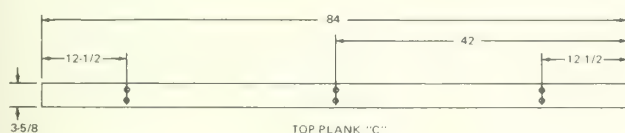
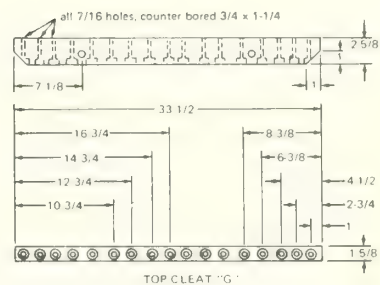
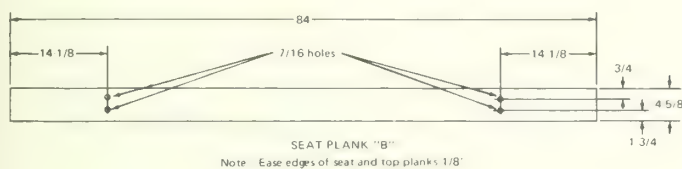
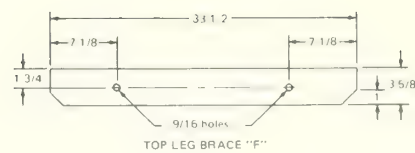
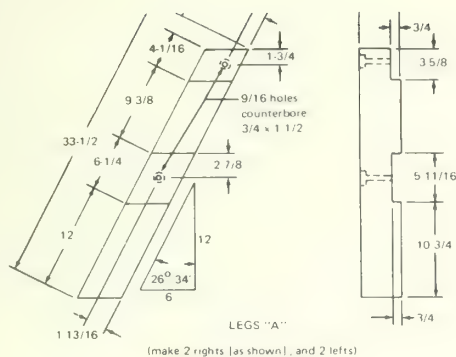
When cutting and boring is completed, the legs shall be given a preservative treatment by soaking for 48 hours, and all other parts for 7 hours, in a water repellent preservative certified as conforming to composition A (pentachlorophenol) of Federal Specification TT - W - 572, 'Wood Preservative, Water Repellent.' One brush coat of the Forest Products Laboratory Natural Finish, colored to Regional Standards, shall be applied after assembly. The interval between treating and applying the finish shall be such that the surface shall be free from waxy, greasy, oily, or crystalline deposits removable by rubbing with the fingers, free from any glossy film resembling that of varnish, and free from any easily detectable odor of treating solvent. If the only surface contamination is in the form of a few dry crystals that can readily be removed by brushing, finishing may be permitted if the surfaces are brushed clean.

Wood seat and top planks shall be installed with the heart side down.

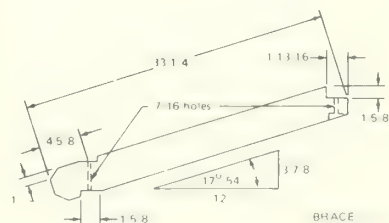
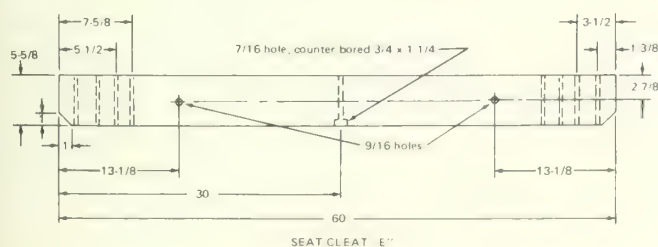
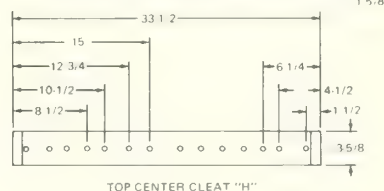
Before mass production of this unit is started, a pilot model should be cut and assembled to assure proper dimension and fit.

HARDWOOD LIGHT PLANK TABLE  
developed by the  
USDA FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION  
and SOUTHERN ILLINOIS UNIVERSITY

Figure 2.--Plan for Forest Service light-plank table. (Lumber sizes may vary by producer and amount of seasoning; if finished board widths and thicknesses different than those shown are used, the plan will have to be adjusted accordingly.)



Note: Lay out top planks in proper sequence with 3/8" space between planks; then using cleats G and H as predrilling templates, predrill 5/16" by 1" deep.



Red oak and hickory lumber (No. 2 Common and No. 3A Common grades, 8/4-in.) in random widths 8 to 16 ft long is satis-

factory, but the highest yield and best balance of parts for 7-ft tables will be obtained from 14-ft lumber. Legs can be

made from Sound Square Edge grade<sup>1</sup> timbers air-dried to less than 19 percent moisture content. Allowable defects (see Appendix) will of course be more numerous in parts produced from No. 3A Common lumber than from No. 2 Common lumber, but such defects do not detract from either the appearance or the utility of the finished tables.

The costs per table for materials and direct labor range from about \$45 to \$53 (table 1). Not included are indirect costs that could vary greatly by individual manufacturing plants: depreciation; maintenance of woodworking machinery; and plant, utilities, supervisory, and overhead costs.

or better factory-grade lumber. This makes it easier to obtain the longer cuttings for the tabletop and seat planks. The Sound Square Edge grade in random lengths costs about the same as No. 2 Common lumber of fixed length.

Cost of material other than lumber depends on the size and design of the table. This is true of hardware, finishing materials, and the preservative. Hardware costs average \$9 per table for galvanized bolts, nuts, washers, and lag screws. The tables require an average of 0.2 gal of the natural-finish stain (USDA Forest Products Laboratory 1961) at a cost of about \$1 per

Table 1.--Average costs of materials and direct labor per table, 1974

(In dollars)

Materials	RED OAK			
	Grade and length of lumber			
	No. 2 Common		No. 3A Common	
	Random : length	14-ft : length	Random : length	14-ft : length
8/4-in. lumber <sup>1</sup>	26	28	27	27
4- by 4-in. timbers <sup>1</sup>	4	4	4	4
Hardware	9	9	9	9
Finishing stain	1	1	1	1
Preservative	1	1	1	1
Labor <sup>2</sup>	10	10	11	10
Total	51	53	53	52
	HICKORY			
	Grade and length of lumber			
	No. 2 Common		No. 3A Common	
	Random : length	14-ft : length	Random : length	14-ft : length
8/4-in. lumber <sup>1</sup>	22	20	22	20
4- by 4-in. timbers <sup>1</sup>	3	3	3	3
Hardware	9	9	9	9
Finishing stain	1	1	1	1
Preservative	1	1	1	1
Labor <sup>2</sup>	11	11	11	11
Total	47	45	47	45

<sup>1</sup>Figures from table 2.

<sup>2</sup>At an average labor charge of \$2.25/hr.

The cost of lumber and timbers per table and the yield of table parts varies with species, grade, and length (tables 1 and 2). One way to lower the cost of hardwood tables is to use Sound Square Edge lumber and timbers. This grade of thick oak and hickory is often easier to obtain from local sawmills than the No. 2 and No. 3A Common factory grades, and we have found that the Sound Square Edge grade contains some boards equivalent to No. 1 Common

table. The average cost of preservative is also about \$1 per table (table 1).

At an average of \$2.25/hr each for two laborers, the total cost of direct labor per table ranges from \$10 to \$11. In terms of labor, the cheapest lumber to convert to table parts is the No. 2 Common, 14-ft red oak and the most expensive is the No. 3A Common, random-length hickory.

All wood for tables should be seasoned to less than 20 percent moisture content before fabrication and preservative treatment. To produce tables efficiently, a shop should be equipped with a cut-off saw

<sup>1</sup>These timbers may be supplied by local mill operators who define the Sound Square Edge grade as being free of wane, unsound defects, shake, and pith.

Table 2.--Yield of table parts and cost of lumber and timbers, 1974

RED OAK					
Grade, thickness, and length	Yield	Input required for 12 tables	Price per thousand board feet delivered	Cost for 12 tables	Cost per table <sup>1</sup>
	Percent	Board feet	Dollars	Dollars	Dollars
No. 2 Common, 8/4-in., random-length lumber	50	1,890	165	312	26
No. 2 Common, 8/4-in., 14-ft-length lumber	52	1,867	180	336	28
No. 3A Common, 8/4-in., random-length lumber	44	2,160	150	324	27
No. 3A Common, 8/4-in., 14-ft-length lumber	48	1,964	165	324	27
Sound Square Edge, 4- by 4-in., 8 to 12 ft timbers	75	270	175	48	4
HICKORY					
No. 2 Common, 8/4-in., random-length lumber	43	2,200	120	264	22
No. 2 Common, 8/4-in., 14-ft-length lumber	54	1,778	135	240	20
No. 3A Common, 8/4-in., random-length lumber	40	2,400	110	264	22
No. 3A Common, 8/4-in., 14-ft-length lumber	48	2,000	120	240	20
Sound Square Edge, 4- by 4-in., 8 to 12 ft timbers	75	270	135	36	3

<sup>1</sup>To determine the total cost per table, add the cost of the 8/4-in. lumber to the cost of the 4- by 4-in. timbers of the same species.

straight-line rip saw, jointer, surfacer, table saw, radial arm saw, bandsaw, and floor-type drill press.

Red oak and hickory are not naturally durable woods, so table parts should be preservatively treated after fabrication and before assembly (see Appendix). Good construction principles pay off in long service. Tables should be assembled, after predrilling for screws and bolts, so that seat and top planks are installed with the bark side up. The bark side is less likely to shell with alternate wetting and drying during exposure. Bolt heads should be driven flush with the boards, but crushing should be avoided. Crushed grain will eventually lead to loose bolts, debris collection under the bolt heads, and water collection and decay.

Hardwood picnic tables are easy to maintain, especially if kept in continuous shade. Penta-fortified water-repellent stain finish should last at least 2 years on shaded tables. Do not scrub with a strong detergent. Scrubbing lifts the

finish, exposing the wood to extremes of wetting and drying, promotes serious checking, and ruins the appearance of the table (Cooper 1968). Remove spilled foods, dirt, dust, and bird droppings with a stiff dry brush. Most picnickers use a tablecloth or paper under their food and do not expect outdoor equipment to be sterile. Minor repairs, including tightening bolts and nuts, are usually needed every 2 years.

Hickory and red oak picnic tables tested under heavy use for 10 years on National Forest recreation areas have given good service and are still in good condition. Furthermore, they were more durable than comparable softwood tables.

#### A Children's Table (Cooper 1964)

An attractive and sturdy picnic table for children can be made from hardwood lumber for \$10 or less. Its two seats will comfortably accommodate four children, and it will not tip if weight becomes unbalanced between the two sides (figs. 3 and 4).



Figure 3.--*This red oak picnic table for children is unlikely to tip even if the seating becomes unbalanced.*

Hardwoods in the table resist marring and breakage.

The 36- by 45-in. table requires only 15 board feet of wood parts (fig. 4) made from air-seasoned, 1-in., No. 2 Common red oak or hickory lumber. The table parts are small, and sound knots can be included, permitting a 70-percent yield of parts. At \$160 per thousand board feet, wood parts would cost less than \$3.50 per table. Preservative, stain, hardware, and direct labor would cost about \$6.20. This total direct cost of about \$9.70 per table could be reduced in a commercial shop if the tables were mass-produced.

Preservative treatment of the table parts will prevent decay and insect damage and add years of life if tables are used outdoors. Parts should be cut to size and drilled and then treated by dipping for 5 min in a 5-percent solution of water-repellent pentachlorophenol preservative in mineral spirits.

If the table will be used inside, it can be finished with a stain, then lacquered or varnished. Stain can be omitted if a natural wood color is desired.

#### Movable Benches

A comfortable bench 5 ft long (figs. 5 and 6) requires 41 board feet of wood parts cut from red oak or hickory 8/4-in., No. 2

Common, air-dried lumber (Cooper 1963b). This rough lumber costs about \$165 per thousand board feet (1974). Assuming a 60-percent yield of usable cuttings, wood parts for this bench would cost \$11.30. Benches can be built for less than \$22 each for direct labor and all materials in a plant equipped to crosscut, rip, plane, and drill hardwood lumber.

The wood parts listed in the bill of materials (see plan and Appendix) can include sound defects such as stain, wormholes, and tight knots 1/4 in. in diameter or smaller. Normal surface checks are also permissible.

Completed parts should be treated with a water-repellent preservative (see Appendix). When the parts have dried, the bench can be assembled with ordinary handtools. All flat-grain planks and armrests should be installed with the bark side of the board upward to reduce splintering and shelling. After assembly, the bench should be coated with a natural finish penetrating stain, preferably a water-repellent preservative type with double-strength pigments (see Appendix). This stain does not form a film, hence the benches are easy to refinish.

The bench will seat three persons comfortably. If a longer bench is needed, seat and back planks can be increased 18 in. in length to provide a four-seat bench. No alterations in the legs, armrests, or cleats would be necessary.

These benches can be easily produced in conjunction with large hardwood picnic tables. The part sizes are compatible and in many cases bench parts can be made from pieces left over from table production.

#### Stationary Benches (Landt 1971)

Another style of bench, suitable in heavy-use areas or where a permanent location is desired, has a concrete base with 7-ft hardwood slats (figs. 7 and 8).

Hickory costs about the same as oak for practically defect-free bench slats. Even though the yield of slats from No. 2 Common hickory is less (39 percent) than red oak (54 percent) and the machining costs for hickory are greater, the lumber costs offset the differences and the per-slat cost for both woods is about \$2.75

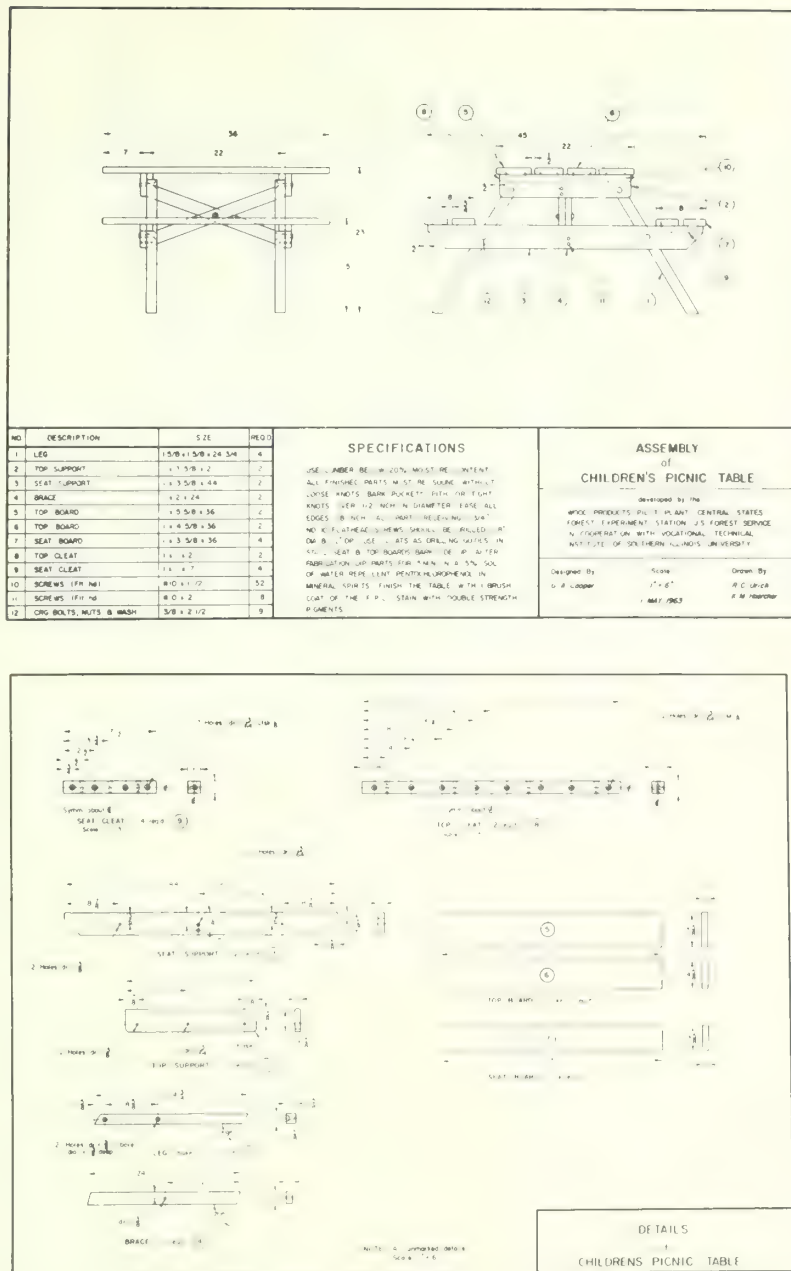


Figure 4.--Plan for Forest Service children's picnic table.

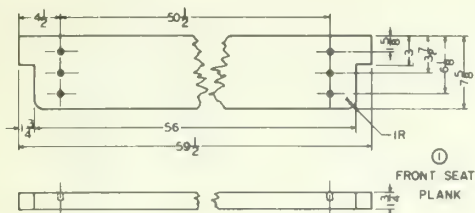
(1974). This does not include indirect costs such as overhead and depreciation.

We recommend the concave bench design, lumber that has minor defects located only in the center of the slats, and soak-treating

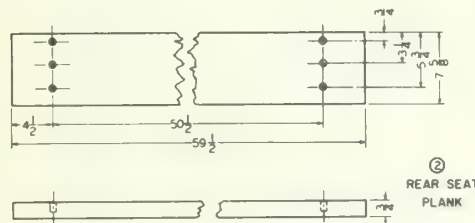
with a 5-percent pentachlorophenol water-repellent solution and brush retreating after 2 years of service.

Although both red oak and hickory, even when treated, check when exposed, they

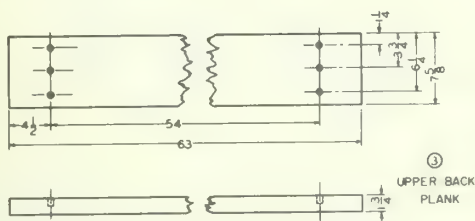




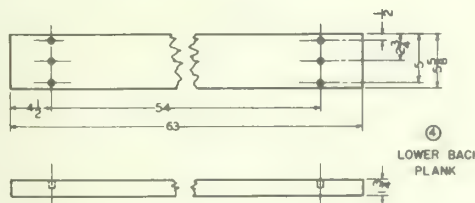
ALL HOLES ARE DRILLED  $\frac{3}{8}$  DIAMETER  $\frac{7}{8}$  DEEP  
FROM THE HEART SIDE



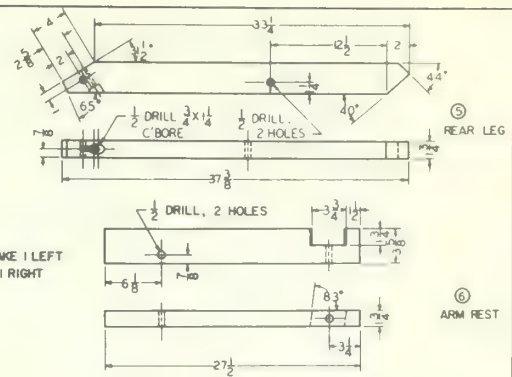
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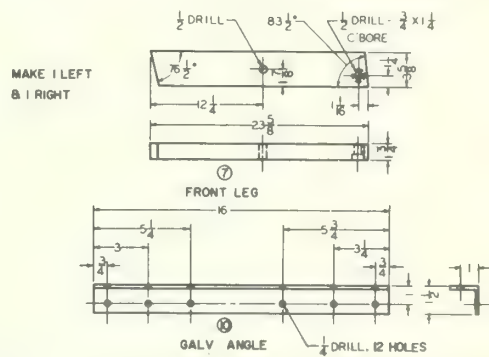
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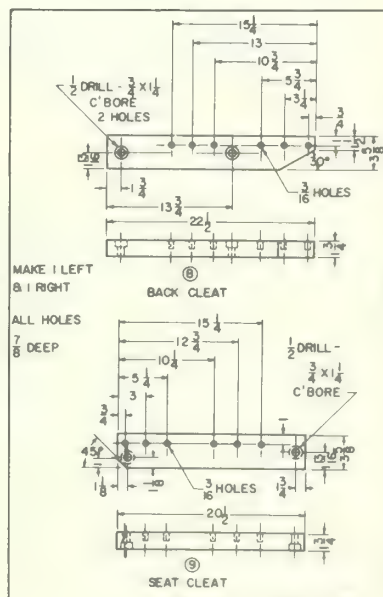
ALL HOLES ARE DRILLED  $\frac{3}{8}$  DIAMETER  $\frac{7}{8}$  DEEP  
FROM THE HEART SIDE.



MAKE 1 LEFT  
& 1 RIGHT



MAKE 1 LEFT  
& 1 RIGHT



MAKE 1 LEFT  
& 1 RIGHT

ALL HOLES  
 $\frac{7}{8}$  DEEP



Figure 7.--Forest Service wood-slat outdoor benches are used extensively at Southern Illinois University.

weather with an attractive texture and become a mellow light to dark gray color. Untreated slats weather to a darker gray and mottled surface and are less attractive.

Defects in the lumber and location of the defects within the slats affect weathering resistance. Slats with few defects are more resistant to weathering than slats with many defects. Especially serious are defects such as knots located on the slat edge or end. Generally, sound, intergrown knots located near the middle of the slat do not detract from its use in the bench. Surfaces free of defects develop almost no splinters or rough areas.

Both red oak and hickory slats are more resistant to vandalism than those made from softwoods. This advantage, along with the characteristic weathering pattern that gives surfaces an attractive texture, makes red oak and hickory especially suitable for outdoor benches of this style.

#### A Hardwood Picnic Shelter (Rice 1964)

Another outdoor facility that can be made from hardwood lumber is a picnic shelter. Our design for an attractive, sturdy, easily maintained shelter can also be used for a carport (fig. 9). The parts for this shelter can be fabricated either in a woodworking shop or on the site where it is to be erected.

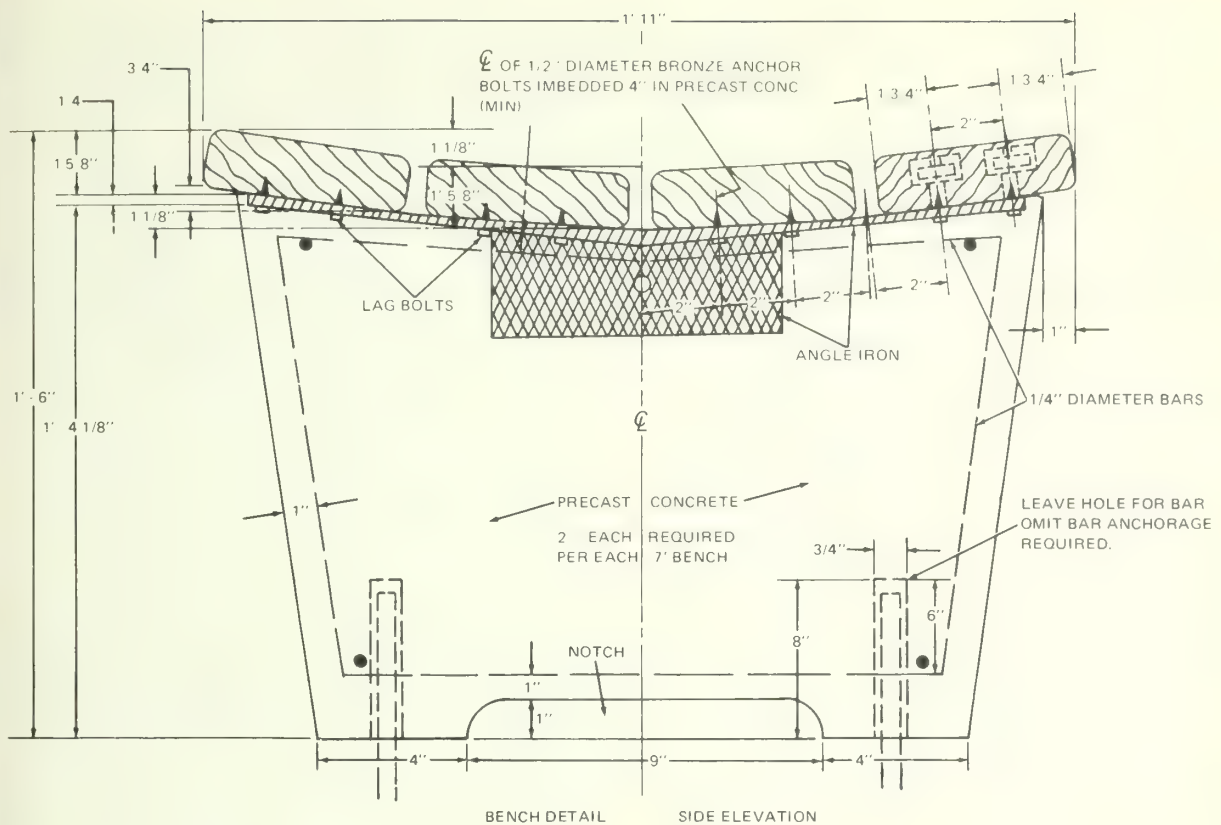


Figure 8.--Campus bench using four 1 5/8- by 5 1/2- by 84-in. red oak or hickory slats on concrete legs. The slats are lag bolted from the bottom to an angle iron attached to concrete legs at each end of the bench. The concrete legs have a concave shape on the top so that each slat is pitched slightly from the horizontal plane. This prevents water from standing on the slat and thus helps in drying.



Figure 9.--A picnic shelter made of hardwood lumber.

The plan is based on adaptations of the rigid-frame construction system. The studs and rafters are joined with nail-glued plywood gussets to form an arch. This system is simple, inexpensive, and provides clear spans.

In this 20- by 30-ft shelter, the rigid-frame design is used throughout the length of the building as well as across it, thereby eliminating the need for sidewall bracing. The roof is supported by four rigid, stud-rafter frames spaced 10 ft on center. For the eave beam and remainder of the column, the rigid-frame system is also used. The 34-ft-long eave beams are made by joining together two 12-ft pieces and one 10-ft piece. The columns are 6 ft 9 in. high, and when nailed to the stud-rafter units they form "T"-shaped members. Conventional ridge board and common rafter assemblies, with rafters spaced 2 ft on center, are used in each 10-ft bay. Sheathing and shingles complete the roof. The stud-rafter frames span 16 ft and a cantilever extension of the rafters provides a 2-ft roof overhang. Thus, the usable clear area within the shelter is 16 by 30 ft (480 ft<sup>2</sup>) while the overall roofed area is 20 by 34 feet (680 ft<sup>2</sup>).

The shelter requires approximately 800 board feet of nominal 2-in.-thick, No. 1 Common, oak or hickory lumber for structural members; 1,000 board feet of nominal 1-in.-thick mill run hardwood lumber, such as gum, cottonwood, or soft maple, for roof sheathing; and 80 ft<sup>2</sup> of 3/4-in.-thick exterior type Douglas-fir plywood for gussets (fig. 10). All the lumber should be air-dried to about 20 percent moisture content.

No. 1 Common lumber is usually free of defects that would be objectionable in the structural members. However, precautions must be taken so that knots or other defects do not appear on the edges of the rigid-frame columns, beams, and rafters, especially within 2 ft of the gusset-assembly points.

A wood preservative should be applied to the base of each stud and column before assembly to protect them from insect and decay damage. An effective method is to stand the studs and columns in drums or tubs of a 5-percent solution of pentachlorophenol in mineral spirits for 24 hr. The base of each member needs protection to 1 ft above the concrete pier line.

The length of the shelter can be extended indefinitely by adding bays as long as 10 ft each. But the roof will not safely span more than a 20-ft width unless rafters and columns are strengthened.

An attractive variation is to add a raked roof overhang at the ends of the shelter. This can be done by installing a 5-ft-long end ridge board, one pair of common rafters beyond the end rigid frame, and a pair of 10-ft, 11-1/4-in. end rafters. The longer end rafters are joined to the other rafters by bolts. Angle iron, 2 in. by 2 in. by 5 in. long, and bolts connect the end rafters to the ridge. To prevent sag in the raked overhang, place solid 2-by 6-in. bridging between the rafters. The bridging terminates at the outside of the end rigid frame.

The shelter can be made in less than 200 man-hr using skilled labor at both shop and site. Savings in labor are possible if surfaced dimension stock and roof sheathing are purchased, rather than rough lumber which must be surfaced. Of course, labor savings here will be reflected in the higher material costs when buying presurfaced material.

We estimate that our shelter can be built for as little as \$1,560, allowing \$710 for materials (table 3) and \$850 for labor. We assume that shelter parts are prefabricated in a well equipped shop and erected by skilled workers. These costs do not include machine operation, overhead, and profit.

#### A Hardwood Rustic Cabin (Rice 1965)

This cabin was especially designed to be constructed from hardwood lumber and other materials available at any lumberyard (fig. 11).

A major feature of this cabin is rigid frame construction, a type of assembly that is especially suitable for rustic buildings (fig. 12). The rigid-frame components (arches) are spaced 4 ft on center along the length of the building and wall-panel units are installed between the frames and in the end walls. The wall panels and the rigid frames can be installed on a conventional joist floor system, concrete piers, a foundation wall, or a concrete slab. Vertical board-and-batten siding can be used

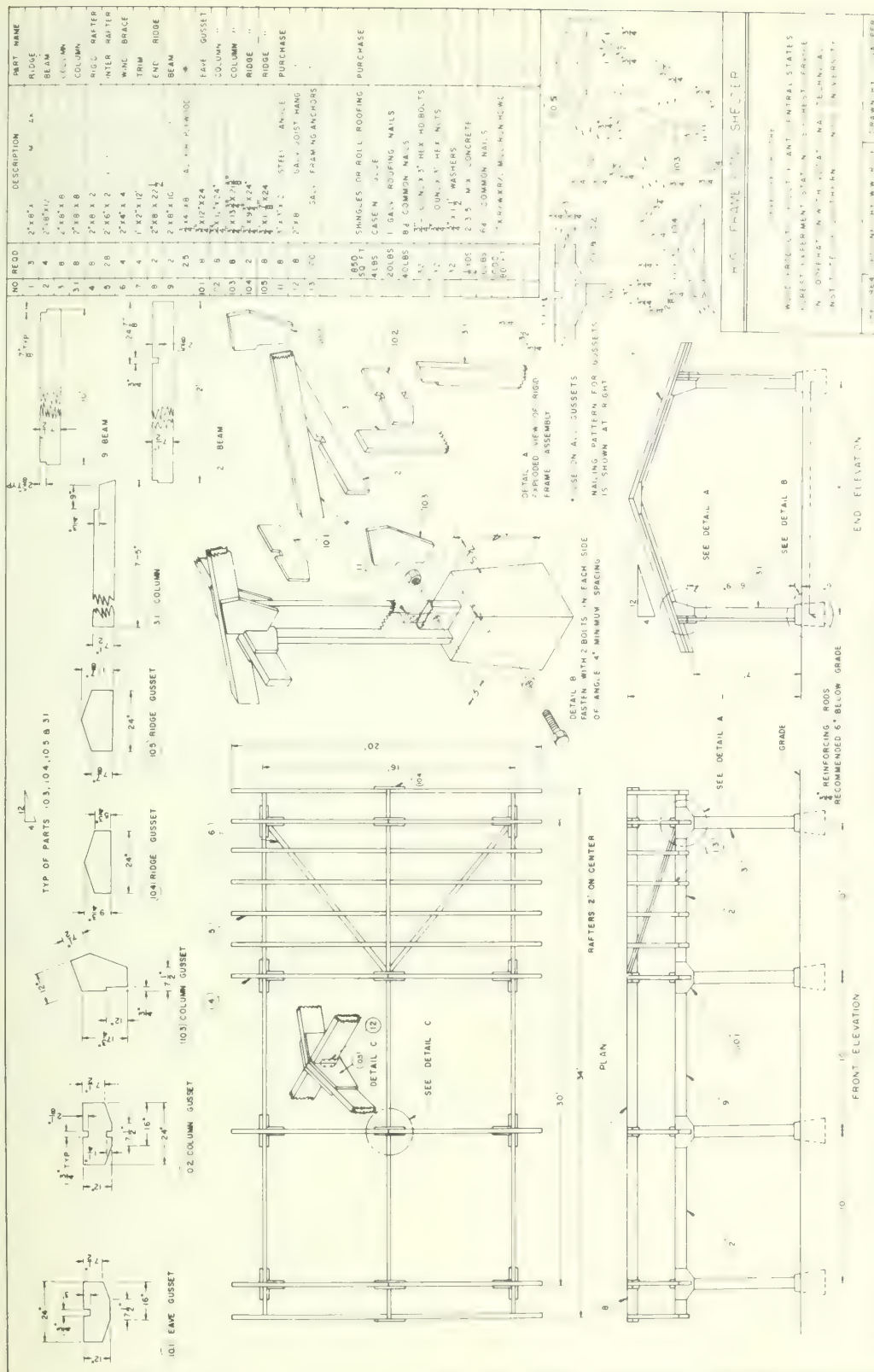


Figure 10.--Plan for a Forest Service rigid-frame picnic shelter.

Table 3.--Material cost for a 20- by 34-ft hardwood picnic shelter, 1974

Item	Amount	Cost
		<i>Dollars</i>
8/4 Framing lumber	800 fbm	224
4/4 Sheathing		
lumber	1,000 fbm	160
3/4 Plywood	80 ft <sup>2</sup>	32
Asphalt shingles	7-2/3 squares	100
Framing anchors		
and nails		64
Concrete	1-1/2 yd	35
Bolts, steel		
parts		40
Wood preserv-		
ative	20 gal	20
Stain	5 gal	35
Total		710

on the exterior (Cooper 1967), and the roof can be sheathed and shingled.

The rigid frames span 17 ft and, by a cantilever extension of the rafters, provide a 2-ft overhang for the roof. Usable clear area within the cabin is 16 by 20 ft (320 ft<sup>2</sup>) with an 8- by 17-ft (136 ft<sup>2</sup>) open porch at one end.

The cabin requires approximately 2,500 board feet of nominal 2-in.-thick, Sound Square Edge grade, oak or hickory lumber for studs and rafters; 1,000 board feet of nominal 1-in.-thick, No. 2A Common, yellow-poplar lumber for siding; 450 board feet of 25/32-in.-thick tongue-and-groove oak flooring; and 600 ft<sup>2</sup> of 3/8-in.- and 3/4-in.-thick Douglas-fir plywood for gussets and subflooring.

It is easy to vary the design of the cabin. For instance, it can be lengthened by adding 4-ft sections. The rigid frames can be made to span 20 ft in width (plus overhang) by lengthening the 2- by 6-in. rafters. Spans greater than 20 ft would require larger rigid-frame members.

The cabin can be made weathertight by installing glass windows in place of screens, closing in the ceiling and insulating the roof, and sheathing and insulating the side walls before applying the board-and-batten siding. Solid wood paneling or sheets of plywood, hardboard, or plasterboard paneling can be easily installed on the interior walls.

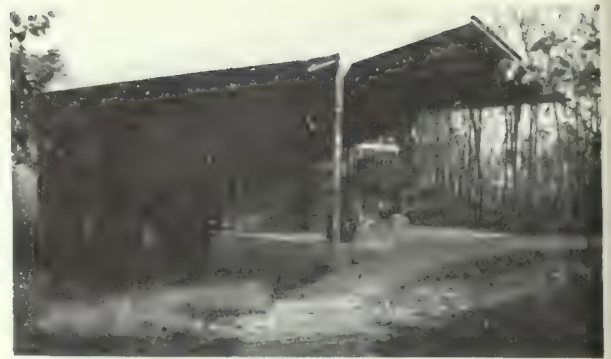


Figure 11.--A rigid-frame cabin made from hardwood lumber.

As designed, the cabin is one large room. However, partitions can be added to form closets and to screen kitchen and sanitary facilities. Plumbing for a kitchen and bathroom can be located wherever desired and installed whenever convenient if the cabin is built on piers or a foundation. Holes for water pipes and drains can be bored through the floor or sill plates without making structural changes in the framing. However, if the cabin is erected on a concrete slab, the plumbing should be in place before the slab is poured.

This cabin can be built for as little as \$2,000 in labor and materials if parts are prefabricated in a well equipped shop and if the cabin is erected by skilled workers. Labor savings are possible if surfaced lumber is used, but at least part of these savings must be used to pay for the ready-to-use material. Siding should be rough on the weather face and dressed on the inner face. Rough lumber stock and siding will cost about \$700.

Siding and framing parts should be preservatively treated to prevent insect damage and decay. Rough exterior faces of the siding should be finished with a water-repellent, penta-fortified stain (see Appendix).

#### Hickory Stadium Seat Slats

Most slat-type and single-board stadium seats have been made from softwoods (Sesco and Kallio 1967); but hardwoods, particularly hickory, have proved equal or superior to softwoods (Micklewright 1960, Sesco and Dunmire 1967).





Hickory seat slats are strong, look good, and are durable when treated with a preservative. Furthermore, they are tough and wear smoothly without splintering. A 10-year service test in a university stadium has shown that hickory seat slats outperform comparable slats made from commonly used softwood lumber (fig. 13).



Figure 13.--These hickory seat slats in McAndrew Stadium at Southern Illinois University outlasted softwood slats installed at the same time.

Hickory seat slats can be produced at reasonable cost. Experimental hickory slats, made from No. 2 Common lumber, average about \$1 per seat (18-in. seat width) in direct cost. We believe that this cost is low enough to allow for indirect costs and still provide a reasonable profit margin.

Slat-type seats generally consist of two 2- by 6-in., three 2- by 4-in., or three 2- by 3-in. slats fastened to metal supports anchored to a concrete or steel substructure (Sesco and Kallio 1967). Slats should be made according to the specifications for acceptable and unacceptable defects given in the Appendix, and they should be treated with a wood preservative before painting. If unpainted, they should be brush-treated biennially in-place.

#### Hardwoods for Rustic Signs (Cooper 1969)

Most recreation area signs are rustic in style and made of materials selected for their beauty, utility, and availability. Usually wood or wood-based materials are

used, the letters are routed, and the boards are stained or enameled. Some rustic signs have artwork. All exterior signs are subjected to sun, rain, wind, decay, insects, and vandals. Many of them must be refurbished or replaced after only 2 years.

Sign durability depends on the construction material, how the sign is made and finished, and the severity of the environment. Wood and finishes vary greatly in durability, depending on the exposure conditions, so it is important for sign manufacturers to know the exposure hazards and their effects.

Processing rustic hardwood signboards begins with the wood selection. How dry the wood is, its grade, the grain orientation, and the species characteristics must all be considered.

Slat signs should be made without knots and if possible from vertical-grain boards. Material should be seasoned to the moisture content the signs would be expected to average in service, usually 12 to 18 percent. Hardwoods should be treated with a water-repellent preservative to help prime the wood and prevent decay.

Wood properties and performance characteristics differ among and within wood species (table 4). The wood properties important to signbuilders are: (1) the ease of routing and working, (2) glueability, (3) natural durability or ease of preservative treatment, (4) finishing characteristics, (5) the occurrence of extractive stains and resins and their effect on finishes, (6) dimensional stability, and (7) resistance to checking and raised and loosened grain. Several hardwoods that we tested have been rated in each of these categories (table 4).

Signboards that do not rout easily should not be dismissed from selection. Some wood substrates that are difficult to rout without burring the edges are otherwise suitable for signboards. Basswood and soft maple sometimes do not rout cleanly, but they are relatively stable and hold finishes well. Blackgum and red oak rout fairly well, but blackgum warps and red oak face- and end-checks. The best hardwood for signs is yellow-poplar which has excellent machining characteristics and holds finishes well (fig. 14).

Table 4.--Characteristics of tested signboard wood materials for  
routed, rustic, flat-grained, slat signs

Material	Ease of routing	Ease of working	Ease of gluing	Ease of drying	Natural durability	Type of treatment	Finish-holding ability	Dimensional stability	Resistance to checking	Resistance to loosening of grain	Remarks	Overall rating for routed signs
Cottonwood	Poor: woods up	Difficult	Easy	Easy	Very low	Moderate	Poor	Poor	Poor	Very high	Routs very poorly	Not recommended
Red alder	Good	Easy	Easy	Easy	Low	Good	Good	Poor	Poor	Very high	Cups, checks	Not recommended
Red oak	Good	Fair	Moderate	Moderate	Low	Easy	Fair	Poor	Poor	High	Excessive checking	Not recommended
Yellow-poplar	Excellent	Easy	Easy	Easy	Low	Difficult	Very good	Good	Good	Very high	--	Good
Soft maple	Moderate	Fairly easy	Moderate	Moderate	Low	Moderate	Fair to good	Fair	Poor	Moderate	--	Fair
Basswood	Moderate: burrs	Easy	Easy	Easy	Low	Easy	Very good	Good	Good	Very high	--	Fair
Blackgum	Poor: burrs	Difficult	Difficult	Difficult	Low	Easy	Very good	Poor	Poor	Very high	Twists frequently	Not recommended



Figure 14.--After 4 years of exposure, this yellow-poplar sign slat is in good shape even though the water-repellent stain has eroded and exposed some bare wood. The sign can be easily refurbished to be more durable than originally. Paints and enamels last longer on yellow-poplar but are more difficult to refurbish than stains.

How well finishes perform depends on several factors: the kind of wood used, the type of finish used, and how the finish is applied. The lighter hardwoods hold coatings longer than the dense hardwoods. Furthermore, hardwoods with fine pores hold coatings better than hardwoods that have large pores. So it is often necessary to apply a filler to large-pored hardwoods, such as oak, so coatings can bridge the pores.

If high-quality enamels with good priming are spray- or roller-applied, the recommended woods should give at least 4 years of service. Some emulsion paints will not dry quickly and may fail early in wet climates. Lacquers are brittle and fail early, and clear coatings break down sooner than pigmented coatings in sunlight. Where a rustic appearance is desired, a pigmented water-repellent stain applied to rough-sawn wood gives excellent results. It is easily applied, and after some weathering a second coat can be rolled on and will be more durable than the first. Every finish varies according to the manufacturer and should be tested and judged on its own merits on the intended substrate and in the environment where it must serve.

## SUMMARY

Recreation structures made from hardwoods have been designed, built, tested, and found very suitable for heavily used recreation areas. The heavy hardwood resists vandalism and wear and, when properly preserved, finished, and maintained, will give many years of service.

Hardwoods for outdoor structures should be air-dried to 20 percent moisture content or less before fabrication. Small knots and sound intergrown knots in the center of parts do not detract from the utility and performance of the wood, thus permitting high part yields from No. 2 Common and No. 3 Common grades of lumber. Knots and defects on edges should be avoided. Parts should be installed with the bark side up, they should be preservatively treated, and they should be finished with a penta-fortified pigmented stain.

The fast-growing demand for outdoor recreation sites and equipment is creating new opportunities for the hardwood industry. Outdoor recreation is expected to increase; and there will be a vast program of construction, expansion, and rehabilitation of facilities requiring lumber or substitute materials (Sesco 1969).

The high cost of softwood construction lumber and the superior service provided by hardwoods for many recreation structures brighten the outlook for utilization of low-grade hardwoods. It is up to the people who manage recreation areas and provide the maintenance and structures for them to seek the lower cost, more durable way. And it is the responsibility of industry to use the lower grades of lumber to advantage.

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## APPENDIX

### PURCHASING HARDWOODS

Besides the woods mentioned in the plans for each structure, several other hardwoods will serve well (table 5). Some woods, however, are not well suited for some purposes. For example, where strong, stiff members are needed, as in rafters, joists, and trusses, a soft hardwood such as cottonwood should not be used. Furthermore, a wood that is unstable with changing moisture content, such as blackgum, would be less desirable than the oaks and yellow-poplar. Soft hardwoods should not be used for flooring, but they serve well for sheathing.

In addition to selection of the species to purchase, prospective buyers must know the grade, size, and condition of their lumber. Grades are spelled out for each product, but the lower grades generally yield fewer and smaller parts. The best yields and grade use have been determined in the development of the plans, and the user will usually receive the most yield for the money from the recommended grades. A complete description of the lumber grades is available from the industry (National Hardwood Lumber Association 1974).

Hardwood is usually available at sawmills rough sawn only. A few mills also surface hardwoods, but buyers must pay extra for this service. Furthermore, hardwood lumber is seldom kiln-dried--it may be only

partially air-dried or it may be thoroughly air-dried, which is most suitable for recreation products. Avoid lumber that has been kiln-dried below 12 percent moisture content; it will cost more and is too dry for outdoor use.

The purchaser of rough-sawn, air-dried lumber must have planers and surfacers to dress faces, and saws to rip to specified widths as well as to crosscut. Hardwood lumber is cut random widths and random lengths at the sawmill unless a special cutting order is made. Special cutting adds to cost and for most structures is not economical. In general, we recommend that buyers get rough-sawn, air-dried hardwoods of the recommended species and grade and then surface and saw to order in their own plants.

### ALLOWABLE DEFECTS

The following defects, which affect the grade and cost of hardwood lumber, are permissible in many products. Picnic tables, benches, and construction parts for cabins and shelters can be made using surfaced parts that have: stained sapwood; stained heartwood in 25 percent of the piece; pinholes, shotholes, and wormholes not over 1/4 in. in diameter; ordinary seasoning checks; slope of grain not exceeding 1 in 10; occasional skip 1/16 in. deep by 2 ft long; wane not over 1 in. wide and half

Table 5.--Recommended uses for various hardwoods in recreation structures

Species	Structures and uses						
	:	:	:	:	:	:	:
	: Tables,	:	:	:	:	:	:
	: benches,	:	:	: Framing,	:	:	:
	: stadium	: Siding	: Sheathing	: trusses	: Flooring	: Signs	
	: seats	:	:	:	:	:	
American beech			X				
Blackgum			X				
Cottonwood			X				
Hickory	X					X	
Maples, soft			X				X
Oak, red	X	X		X	X		
Oak, white	X			X	X		
River birch			X				
Sweetgum			X				
Sycamore			X				
Yellow-poplar		X	X	X			X

the length on one edge; and sound, tight knots up to 1 in. diameter on 3-in.-wide parts and 1-1/2 in. in diameter on wider parts providing the knots are not on the edges.

Pith, shake, or raised grain, rot, and open bark pockets should not be permitted in the planks. Table legs should be free of pith, shake, and rot; but the following defects may be permitted: wane up to 1 in. wide on any face, and full length; intergrown or tight knots up to 1 in. in diameter; pinholes, shotholes, and spot wormholes; other holes up to 1/4 in. in diameter; and burls, stain, streak, and season checks.

The following specifications for hickory stadium seat slats incorporate the results of several tests (Micklewright 1960).

Unacceptable defects are: splits; knot holes and other holes that extend through the slat or show on the top face; rot; exposed pith; bark pockets larger than 1-1/4 in. on the top face and edges or 1/2 in. deep on any face; wane wider than 1/4 in. on any face; shake; grain slope in excess of 1 in. in 10 in. parallel to the length of the slat; and end-checks deeper than 3/8 in.

Acceptable defects are: burls; stains; streaks; spot; pin wormholes; ordinary seasoning checks; wane up to 1/4 in. wide; bird beak; minor planing skips; torn grain no deeper than 1/16 in. on the bottom face or edges; and any other sound defects that do not reduce strength; sound, tight, intergrown knots up to 1-1/4 in. in diameter and knot clusters up to 2 in. in diameter, except that maximum-size knots should not be closer than 12 in., center to center, within a slat; and any warp (cup, crook, bow, and twist) that can be eliminated by clamping the slat in place during installation.

## PRESERVATION AND FINISHING

All the products described must be protected from insect damage and decay. Structures in contact with the soil and subjected to alternate wetting and drying are most susceptible. Damage can be prevented by treating with a 5-percent solution of water-repellent pentachlorophenol in light oil or mineral spirits. The pentachlorophenol is toxic to wood-destroying insects and decay organisms, and the

addition of paraffins for water repellency greatly reduces the effects of weathering. When wood is properly treated, it is entirely safe for contact by humans and animals.

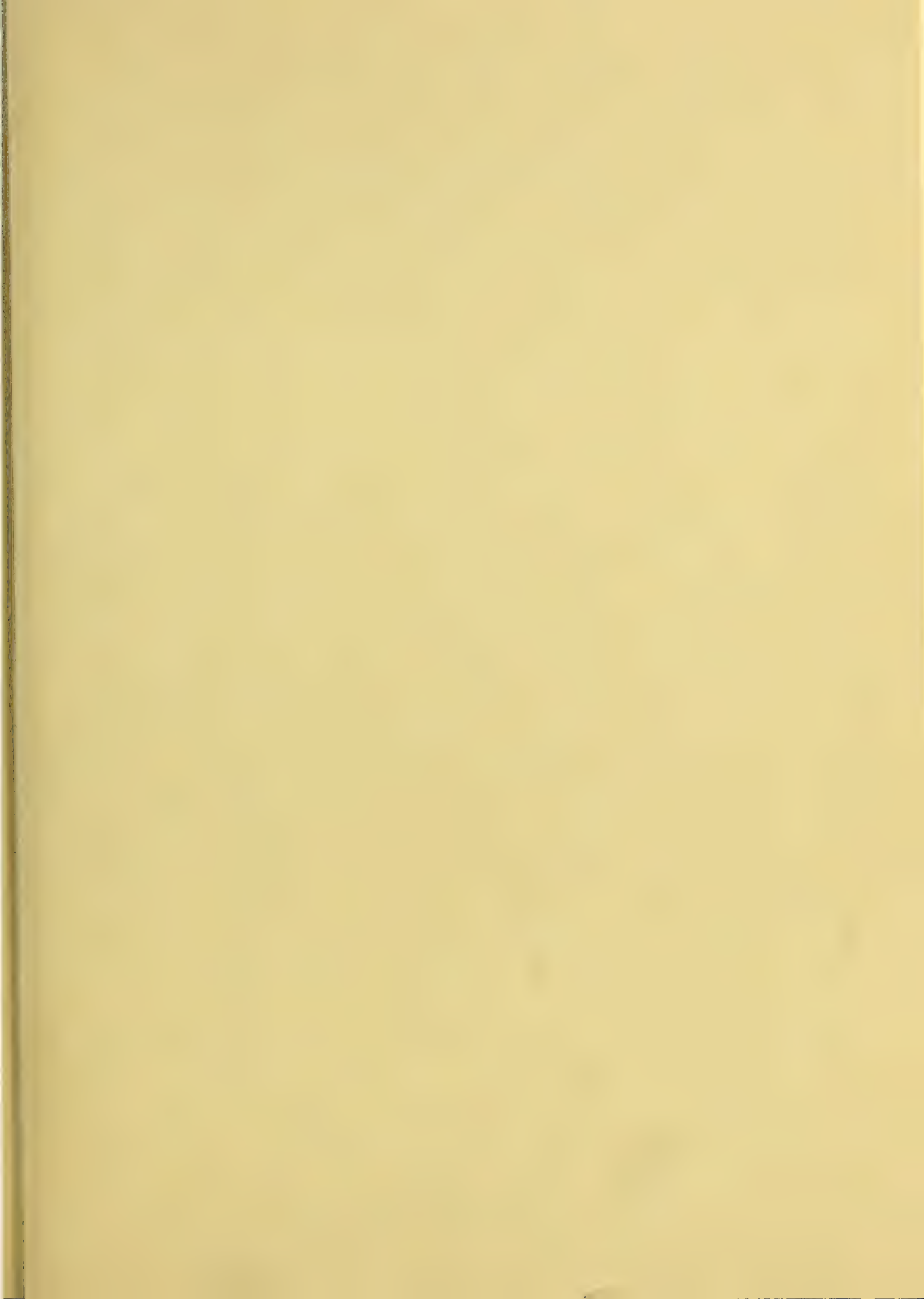
Treatment methods are simple. Once the wood parts are air-dried and completely fabricated, they can be dipped or soaked in a 5-percent solution of water-repellent pentachlorophenol in light oil as specified below:

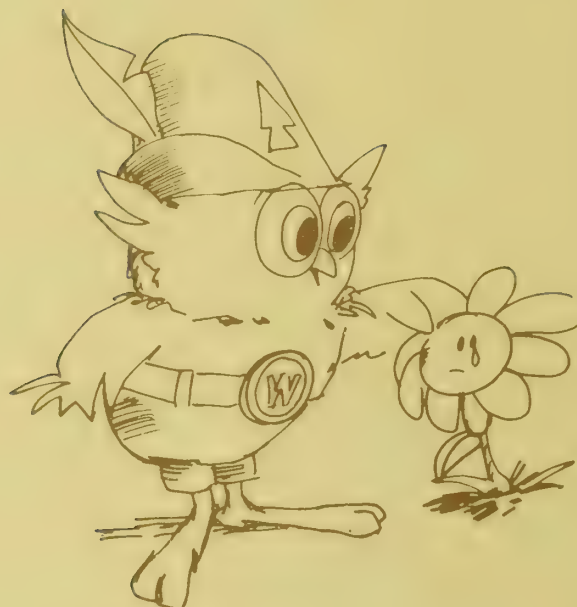
<i>Part</i>	<i>Time</i>
Picnic tables:	
Tops, seats	8 hr
Legs	24 hr
Children's tables	5 min
Movable benches:	
Seats, backs	5 min
Legs	24 hr
Stationary benches	8 hr
Picnic shelter:	
Studs, columns	24 hr
Rustic cabin:	
Rigid-frame columns, joists, girders, plates	24 hr
Other framing	8 hr
Siding, trim	5 min
Stadium seats	8 hr
Signs	5 min

Parts in contact with ground receive long treatment; parts above ground and parts to be sat on need not be treated so long. A tank large enough to submerge the part is all that is necessary. The preservative need not be heated or applied under pressure. Brush away any crystalline deposits on the surface of parts after the preservative dries. Table and bench surfaces are usually safe for contact after treated parts have been exposed to the weather for 30 days. During and immediately after treatment, the wet preservative may cause some skin irritation. The manufacturer's precautions should be followed.

After the preservative has dried, most recreation structures should be finished. Usually a rustic brown or other natural wood color is desirable. The most practical finish is a penta-fortified natural stain that will not peel or flake because it does not form a film. It penetrates the wood and will fade or erode with time, but it is easily refurbished with a light roller application. Such stains can be purchased or homemade (USDA Forest Products Laboratory 1955).







Birds, animals and flowers are dying to tell us...no  
pollution, please!



# local net volume equations for missouri

Equations are in the form of  
the Zimpany model  $Y = S \cdot B^{0.8}$   
 $S = \sqrt{A}$  where the independent  
variable  $X$  and  $S$  are diameter at  
breast height and site index.

by jerold t. hahn

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1975

## LOCAL NET VOLUME EQUATIONS FOR MISSOURI

Jerold T. Hahn

### A P P L I C A T I O N

As a part of the 1972 Forest Survey of Missouri, personnel of the Station's Forest Survey Team developed a merchantable tree volume equation and tables of coefficients for four regions of Missouri. This equation and the coefficients can be used on a digital computer by industrial foresters, consulting foresters, or others in need of quick net-volume-per-tree estimates. The equation and coefficients were developed for both board foot (International 1/4-inch rule) and cubic foot volumes, for several species and species groups, and for two tree classes, "desirable" and "acceptable."<sup>1</sup>

<sup>1</sup>Forest Survey classifies live trees as "desirable," "acceptable," "rough," "rotten," or "short-log." Equations were prepared for the first two classes. Forest Survey defines "desirable" trees as live trees that have no serious defects that limit present or prospective use and that have relatively high vigor and contain no pathogens that may result in death or serious deterioration before rotation age. These are trees that would be favored by forest managers in silvicultural operations. "Acceptable" trees are live trees having no serious defects that limit present or prospective use but that have pathogens or damage that may affect quality. The great majority of the trees in Missouri were classed as "acceptable" with very few "desirable" so the forester wishing to use only one equation for woods-run material would be best advised to use the equation for "acceptable" trees.

The only data needed to determine tree volumes in Missouri with the equation and coefficients are species, d.b.h., tree class, and site index.<sup>2</sup>

To use the equation and coefficients, find on the map the region in Missouri where the trees grow (fig. 1). Next, decide whether you want cubic or board foot volume, and decide what tree class (desirable or acceptable) the trees fall into. Then choose the appropriate table (tables 1 to 4), and the proper region (Survey Unit) within it.

Columns 1 through 6 in the tables contain all the information needed for using the equation except d.b.h. The coefficients (columns 2 through 5) to be substituted in the equation depend on the species group number (column 1), so first obtain this number from table 5. Then substitute in the following equation the appropriate coefficient A (column 2), site index (column 6 if site index was not measured in the field), coefficient B (column 3), coefficient C (column 4), coefficient D (column 5), and d.b.h.

$$\text{Volume} = (A \cdot \text{site index}) \cdot B^C \cdot D^{\text{DBH}}$$

<sup>2</sup>If site index measurements have not been taken, the average site index for the observations used in constructing tables 1 to 4 can be used. These average site indexes are found in column 6 of the tables.



Table 1.--Cubic foot volume regression coefficients for desirable trees,  
Missouri, 1972

EASTERN OZARKS UNIT								
Species :	Coefficient				Average :	Obser- :	Sampling :	R <sup>2</sup>
group :	A :	B :	C :	D :	site :	vations :	error :	
number :	(1) <sup>1</sup> :	(2) :	(3) :	(4) :	(5) :	(6) :	(7) :	(8) :
							No.	Cu. ft.
1- 5	11.70	0.00076	1.42	-0.15	58	67	4.17	0.89
6- 7	1.24	.00081	1.62	- .27	60	118	2.87	.91
8-10	10.16	.00090	1.38	- .16	63	279	3.95	.87
11-12	1.96	.00124	1.58	- .21	69	32	2.68	.92
13-28	2.50	.00055	1.59	- .22	72	25	4.12	.94
WESTERN OZARKS UNIT								
1- 5	7.42	0.00149	1.41	-0.17	57	12	3.87	0.89
6	1.24	.00074	1.64	- .26	59	42	4.56	.82
7	4.35	.00092	1.48	- .19	54	25	3.60	.90
8-10	1.63	.00137	1.58	- .23	64	85	3.87	.90
11-12	2.79	.00294	1.49	- .20	61	15	4.64	.87
13-27	9.28	.00259	1.36	- .15	69	31	6.68	.95
PRAIRIE UNIT								
6-12	5.53	0.0042	1.37	-0.16	61	39	12.50	0.86
13-27	7.57	.0009	1.35	- .18	80	41	10.45	.84
RIVERBORDER AND BOTTOMLANDS UNITS								
1- 5	3.50	0.00033	1.48	-0.19	79	29	7.25	0.98
6- 7	3.30	.00465	1.46	- .19	51	145	6.15	.84
8-10	28.25	.00052	1.31	- .15	57	76	8.38	.92
11-12	1.54	.00086	1.63	- .24	65	36	6.92	.88
13-26	9.64	.00080	1.42	- .15	81	78	7.83	.92

<sup>1</sup>Numbers in parentheses are the column numbers.

Table 2.--Board foot volume regression coefficients for desirable trees,  
Missouri, 1972

EASTERN OZARKS UNIT								
Species :	Coefficient				Average :	Obser- :	Sampling :	
group :					site :	ventions :	error :	R <sup>2</sup>
number :	A :	B :	C :	D :	index :			
(1) <sup>1</sup> :	(2) :	(3) :	(4) :	(5) :	(6) :	(7) :	(8) :	(9)
						No.	Bd. ft.	
1- 5	168.15	0.00021	1.23	-0.23	59	53	31.83	0.84
6- 7	10.49	.00118	1.36	- .34	61	53	24.32	.78
8-10	123.30	.00038	1.23	- .23	64	174	29.74	.76
11-12	31.05	.00040	1.29	- .29	72	20	20.68	.87
13-27	12.00	.00006	1.40	- .37	74	16	36.12	.84
WESTERN OZARKS UNIT								
1- 5	261.90	0.00029	1.26	-0.17	59	10	19.14	0.94
6- 7	4.00	.00005	1.70	- .40	55	37	27.25	.65
8-10	10.06	.00090	1.46	- .28	64	54	28.74	.82
11-12	5.07	.00024	1.60	- .35	65	11	32.30	.73
13-27	39.20	.00073	1.34	- .21	72	23	48.90	.94
PRAIRIE UNIT								
6-12	162.77	0.0012	1.18	-0.18	63	30	103.18	0.73
13-27	232.56	.0002	1.20	- .20	80	37	67.94	.93
RIVERBORDER AND BOTTOMLANDS UNITS								
1- 5	10.55	0.00002	1.56	-0.24	90	15	61.18	0.94
6- 7	14.70	.00578	1.31	- .29	52	111	38.38	.75
8-10	120.13	.00078	1.22	- .22	57	61	51.53	.90
11-12	11.09	.00040	1.32	- .41	68	21	32.30	.53
13-27	48.35	.00031	1.31	- .23	82	75	90.23	.88

<sup>1</sup>Numbers in parentheses are the column numbers.

Table 3.--Cubic foot volume regression coefficients for acceptable trees,  
Missouri, 1972

EASTERN OZARKS UNIT									
Species : group : number : (1) <sup>1</sup>	Coefficient				Average : site : index :	Obser- : vations :	Sampling : error :	R <sup>2</sup>	
	A :	B :	C :	D :	(6)	(7)	(8)	(9)	
	(2)	(3)	(4)	(5)		No.	Cu. ft.		
1- 5	1.89	0.00085	1.56	-0.23	60	597	1.92	0.93	
6	23.38	.00065	1.34	- .12	60	955	4.75	.86	
7	1.47	.00261	1.51	- .22	55	382	2.58	.90	
8	18.91	.00095	1.34	- .13	60	84	6.89	.84	
9	1.41	.00077	1.58	- .25	63	1,555	5.74	.79	
10	1.16	.00144	1.61	- .24	56	67	2.02	.93	
11	1.49	.00038	1.62	- .25	63	144	2.52	.89	
12	.86	.00038	1.73	- .27	60	240	2.80	.86	
13-23	32.35	.00019	1.34	- .14	73	107	11.20	.90	
24-25	1.37	.00216	1.56	- .22	65	44	3.09	.88	
26-27	4.19	.00075	1.45	- .19	64	83	3.23	.89	
WESTERN OZARKS UNIT									
1	4.99	0.00071	1.47	-0.19	58	216	2.50	0.89	
4	21.11	.00022	1.39	- .16	43	40	1.24	.68	
6	1.34	.00092	1.62	- .24	57	530	4.02	.86	
7	1.45	.00183	1.57	- .22	52	569	3.14	.84	
8	13.50	.00046	1.38	- .16	58	95	4.28	.95	
9	3.41	.00189	1.45	- .18	61	862	5.60	.87	
10	2.54	.00155	1.48	- .20	56	94	3.85	.93	
11	3.65	.00154	1.44	- .18	65	78	3.05	.95	
12	2.22	.00092	1.54	- .21	55	139	2.18	.94	
13-17	1.17	.00054	1.66	- .25	68	29	3.83	.88	
18-21	18.74	.00070	1.33	- .14	67	50	6.07	.95	
22-25	3.61	.00149	1.44	- .18	65	63	3.13	.96	
26-27	14.33	.00042	1.36	- .15	58	34	3.54	.78	
PRAIRIE UNIT									
1- 5	1.27	0.0013	1.78	-0.21	72	--	--	--	
6	2.12	.0028	1.56	- .18	56	361	6.57	0.86	
7	.81	.0009	1.69	- .28	52	71	2.71	.85	
8	2.54	.0005	1.58	- .20	59	42	5.98	.95	
9	4.33	.0011	1.33	- .24	53	137	3.30	.96	
10	4.32	.0007	1.44	- .18	76	96	6.68	.93	
11	1.12	.0022	1.57	- .23	66	104	3.64	.88	
12	1.16	.0021	1.58	- .22	64	51	1.37	.76	
13-14	3.82	.0013	1.45	- .18	78	69	8.01	.95	
15-17	--	--	--	--	--	--	--	--	
18	1.83	.0005	1.59	- .22	70	66	3.45	.93	
19	44.09	.0002	1.31	- .13	75	34	14.90	.96	
20	19.57	.0009	1.32	- .13	81	48	6.54	.98	
21-23	5.10	.0009	1.42	- .17	83	43	4.53	.99	
24-25	.84	.0008	1.67	- .25	66	91	2.91	.90	
26	10.84	.0006	1.35	- .15	71	66	6.11	.94	
27	1.65	.0010	1.53	- .22	65	68	5.41	.86	
RIVERBORDER AND BOTTOMLANDS UNITS									
1- 3	3.50	0.00033	1.48	-0.19	79	29	7.25	0.98	
4	1.27	.00133	1.79	- .21	41	129	1.47	.88	
6	1.69	.00160	1.59	- .23	49	1,124	5.65	.80	
7	2.93	.00257	1.48	- .19	43	437	3.38	.84	
8	3.56	.0095	1.49	- .20	54	196	9.34	.87	
9	6.76	.00136	1.41	- .16	58	439	6.29	.91	
10	4.74	.00108	1.51	- .15	60	52	3.51	.98	
11	4.13	.00113	1.46	- .19	58	193	5.09	.97	
12	5.09	.00094	1.45	- .19	56	142	3.33	.95	
13-15	5.21	.00290	1.37	- .16	59	85	3.48	.94	
16-17	.53	.00126	1.55	- .36	73	37	5.18	.79	
18	44.36	.00037	1.31	- .12	64	120	7.65	.92	
19	7.97	.00006	1.56	- .16	78	59	13.15	.92	
20-21	9.53	.00045	1.47	- .15	92	96	16.84	.98	
22-25	.73	.00045	1.68	- .30	64	78	4.58	.76	
26	25.84	.00029	1.28	- .14	68	98	9.41	.97	
27	1.43	.00009	1.82	- .22	86	243	5.81	.89	

<sup>1</sup>Numbers in parentheses are the column numbers.

Table 4.--Board foot volume regression coefficients for acceptable trees,  
Missouri, 1972

EASTERN OZARKS UNIT								
Species :	Coefficient				Average :	Obser- :	Sampling :	R <sup>2</sup>
group :					site :	ventions :	error :	
number :	A :	B :	C :	D :	index :			
(1) <sup>1</sup> :	(2) :	(3) :	(4) :	(5) :	(6) :	(7) :	(8) :	(9)
						No.	Bd. ft.	
1- 5	18.73	0.00069	1.38	-0.26	61	301	14.74	0.90
6	83.50	.00160	1.19	-.19	61	336	40.43	.68
7	40.86	.00331	1.20	-.20	58	122	26.01	.71
8-10	6.14	.00063	1.46	-.32	63	691	48.62	.55
11-12	11.76	.00794	1.27	-.27	61	103	29.10	.32
13-27	18.16	.00032	1.21	-.41	73	75	35.44	.79
WESTERN OZARKS UNIT								
1- 5	42.61	0.00042	1.36	-0.23	59	109	19.91	0.84
6	7.54	.00082	1.47	-.28	57	249	33.58	.64
7	22.29	.00322	1.31	-.20	52	206	25.91	.56
8	38.18	.00102	1.32	-.20	60	50	49.18	.80
9	10.53	.00191	1.39	-.25	60	395	48.27	.68
10	9.90	.00112	1.42	-.26	60	24	44.93	.85
11	3.98	.00167	1.52	-.31	69	22	15.66	.90
12	5.13	.00005	1.62	-.31	61	29	21.03	.84
13-23	37.59	.00033	1.34	-.21	67	30	58.99	.87
24-27	34.79	.00081	1.31	-.20	67	38	33.73	.87
PRAIRIE UNIT								
1- 5	5.78	0.0012	1.39	-0.40	80	--	--	--
6	10.79	.0036	1.30	-.29	55	211	43.53	0.76
7	6.74	.0261	1.27	-.29	51	21	24.52	.07
8	17.70	.0002	1.39	-.26	58	25	36.17	.56
9	13.39	.0005	1.39	-.27	60	64	37.51	.83
10	9.07	.00009	1.57	-.24	80	61	48.56	.80
11-12	106.40	.0014	1.17	-.18	76	32	37.15	.37
13-14	13.12	.0051	1.18	-.36	80	39	48.76	.89
15-17	--	--	--	--	--	--	--	--
18	7.43	.0000009	1.51	-.37	71	21	21.24	.90
19	135.82	.0006	1.19	-.21	76	29	67.10	.97
20	35.11	.0007	1.18	-.35	82	43	77.98	.87
21-23	10.09	.0014	1.21	-.41	82	23	38.08	.96
24-25	3.95	.0002	1.37	-.48	70	36	30.24	.55
26	12.59	.0003	1.19	-.49	75	29	65.95	.78
27	4.32	.0001	1.39	-.43	71	22	61.52	.43
RIVERBORDER AND BOTTOMLANDS UNITS								
1- 3	10.55	0.00002	1.56	-0.24	90	15	61.18	0.94
4	5.78	.00116	1.39	-.40	45	39	16.06	.56
6	17.48	.00573	1.32	-.22	50	624	61.49	.59
7	4.92	.00122	1.28	-.57	45	117	32.84	.45
8	8.46	.00004	1.36	-.45	54	125	55.56	.72
9-10	30.67	.00267	1.24	-.24	59	222	56.95	.77
11	12.63	.00096	1.32	-.32	64	66	51.18	.91
12	195.92	.00044	1.20	-.20	64	38	41.80	.83
13-17	33.93	.00249	1.22	-.22	71	47	39.61	.76
18	373.89	.00012	1.18	-.19	65	50	70.87	.90
19	219.21	.00015	1.15	-.27	80	44	47.58	.95
20-21	37.82	.00083	1.26	-.26	96	71	185.75	.90
22-25	5.82	.00300	1.35	-.34	69	40	39.11	.58
26	5.13	.00095	1.39	-.34	77	19	19.94	.96
27	8.15	.00003	1.34	-.44	91	110	34.40	.80

<sup>1</sup>Numbers in parentheses are the column numbers.

Table 5.--Species and species group numbers for Missouri trees

Species or species group	Scientific name	Number	Species or species group	Scientific name	Number
<b>Softwoods</b>					
Shortleaf pine	<i>Pinus echinata</i> . . . . .	1	Soft maple	<i>A. rubrum</i> var. <i>rubrum</i> . .	14
Other yellow pines	<i>P. elliotii</i> . . . . .	2		<i>A. saccharinum</i>	
	<i>P. palustris</i>		Beech	<i>Fagus grandifolia</i> . . . .	15
	<i>P. rigida</i>		Sweetgum	<i>Liquidambar styraciflua</i> .	16
	<i>P. virginiana</i>				
Cypress	<i>Taxodium distichum</i> var.		Tupelo and	<i>Nyssa aquatica</i> . . . . .	17
	<i>distichum</i> . . . . .	3	blackgum	<i>N. sylvatica</i> var.	
				<i>sylvatica</i>	
Eastern red cedar	<i>Juniperus virginiana</i> . . .	4		<i>N. sylvatica</i> var.	
				<i>biflora</i>	
All other softwoods . . . . .		5			
			Ash	<i>Fraxinus americana</i> . . . .	18
				<i>F. pennsylvanica</i>	
				<i>F. quadrangulata</i>	
<b>Hardwoods</b>					
White oak A	<i>Quercus alba</i> . . . . .	6	Sycamore	<i>Platanus occidentalis</i> . .	19
	<i>Q. macrocarpa</i>		Cottonwood	<i>Populus deltoides</i> . . . .	20
	<i>Q. michauxii</i>		River birch	<i>Betula nigra</i> . . . . .	21
	<i>Q. muehlenbergii</i>		Yellow-poplar	<i>Liriodendron tulipifera</i> .	22
	<i>Q. bicolor</i>				
	<i>Q. lyrata</i>				
White oak B	<i>Q. stellata</i> var.		Basswood	<i>Tilia americana</i> . . . . .	23
	<i>stellata</i> . . . . .	7	Black walnut	<i>Juglans nigra</i> . . . . .	24
Red oak A	<i>Q. falcata</i> var.		Black cherry	<i>Prunus serotina</i> . . . . .	25
	<i>pagodaefolia</i> . . . . .	8	Elm	<i>Ulmus alata</i> . . . . .	26
	<i>Q. rubra</i>			<i>U. americana</i>	
	<i>Q. shumardii</i>			<i>U. rubra</i>	
Red oak B	<i>Q. coccinea</i> . . . . .	9		<i>U. thomasii</i>	
	<i>Q. falcata</i>				
	<i>Q. velutina</i>				
Red oak C	<i>Q. imbricaria</i> . . . . .	10	All other	<i>Acer negundo</i> . . . . .	27
	<i>Q. marilandica</i>		hardwoods	<i>Aesculus glabra</i>	
	<i>Q. nigra</i>			<i>Betula papyrifera</i> var.	
	<i>Q. nuttallii</i>			<i>papyrifera</i>	
	<i>Q. palustris</i>			<i>Catalpa speciosa</i>	
	<i>Q. phellos</i>			<i>Celtis laevigata</i>	
Hickory A	<i>Carya illinoensis</i> . . . .	11		<i>C. occidentalis</i>	
	<i>C. laciniosa</i>			<i>Cornus florida</i>	
	<i>C. ovata</i>			<i>Diospyros virginiana</i>	
	<i>C. tomentosa</i>			<i>Gleditsia triacanthus</i>	
Hickory B	<i>C. aquatica</i> . . . . .	12		<i>Gymnocladus dioica</i>	
	<i>C. cordiformis</i>			<i>Juglans cinerea</i>	
	<i>C. glabra</i>			<i>Maclura pomifera</i>	
	<i>C. texana</i>			<i>Magnolia acuminata</i>	
Hard maple	<i>Acer nigrum</i> . . . . .	13		<i>Morus rubra</i>	
	<i>A. saccharinum</i>			<i>Robinia pseudoacacia</i>	
				<i>Salix nigra</i>	
				<i>Sassafras albidum</i>	
			Noncommercial hardwoods . . . . .		28

## DOCUMENTATION

Data collected on 13,136 trees in the State were used to develop these volume equations. Measurements taken were site index, tree class, d.b.h., merchantable height, and diameter of the stem at merchantable height. For sawtimber-size trees (9.0+ inches d.b.h. for softwoods, 11.0+ inches for hardwoods), measurements were taken at both the sawtimber and pulpwood limits of merchantability. The field crews also measured and estimated the volume of cull material (both in cubic feet and board feet) in each tree.

The net volume in these trees was then calculated using equations developed by Robert N. Stone<sup>3</sup> based on S. R. Gevorkiantz's "Composite Volume Tables for the Lake States."<sup>4</sup> Stone's equations compute gross volume in a tree from the three measurements--d.b.h., merchantable height, and diameter of the stem at merchantable height. This volume is then corrected for differences in bark thickness between species and the field estimate of cull volume is subtracted to arrive at net volume. If tree heights are tallied while making a local cruise, it

would be advisable to measure bark thickness at the same time and to use either the tables from Gevorkiantz and Olsen (1955) or Stone's equations.

Experience in working with volume-d.b.h. relationships suggested that the best mathematical model for this type of data was the "Gomperz" function  $Y = S \cdot B^{C_{D \cdot X}}$ , where the dependent variable Y is tree net volume, the independent variable X is d.b.h., and the asymptote S is a function of site index ( $S = A \cdot SI$ ). Work with test data and previous State surveys confirmed this belief and the model was used with the Missouri data.

The species groups used in the tables were primarily determined by number of observations available for a group (a minimum number of observations are necessary to form an equation using least-squares estimates) and similarity of bole form of the species within a group. The number of observations, the sampling error, and the  $R^2$  for each regression estimate are shown in columns 7 through 9 (tables 1 to 4).

---

<sup>3</sup>Unpublished data on file at the North Central Forest Experiment Station, St. Paul, Minnesota.

<sup>4</sup>S. R. Gevorkiantz and L. R. Olsen. *Composite volume tables for timber and their application in the Lake States*. Lake States Tech. Bull. 1104, 51 p. 1955.

Hahn, Jerold T.

1975. Local net volume equations for Missouri. North Cent. For. Exp. Stn., St. Paul, Minn. 8 p., illus. (USDA For. Serv. Gen. Tech. Rep. NC-15)

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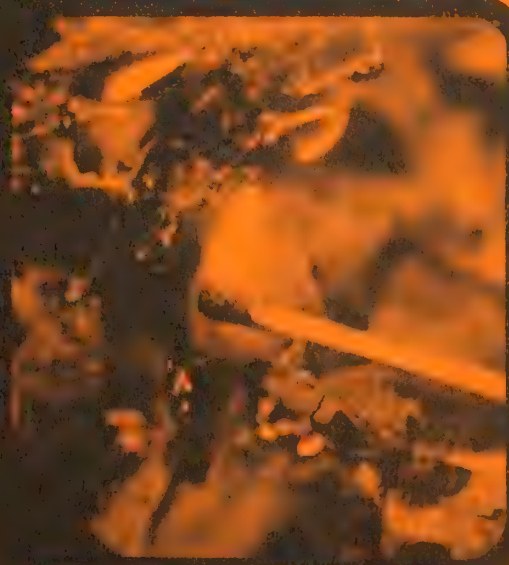
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Plant a tree...trees give oxygen.



wildfire atlas of the northeastern  
and  
north central states



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## FOREWORD

The atlas format used to display the information presented in this report is based on the mapping methodology used by the National Weather Service in "Climatic Atlas of the United States" (National Oceanic and Atmospheric Administration 1968). Most of the weather and climate patterns portrayed in that publication were developed only from data gathered at first-order weather stations. The same principle applies to the patterns portrayed in this paper inasmuch as they were developed solely from data recorded on the National Forests in the north central and northeastern States. Localized pattern variations are minimized using this mapping methodology and regional patterns become apparent. However, the characteristics that become apparent regionally also are applicable to the areas surrounding the geographical points from which the data are taken.

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# WILDFIRE ATLAS OF THE NORTHEASTERN AND NORTH CENTRAL STATES

Donald A. Haines, Von J. Johnson, and William A. Main

## INTRODUCTION

Forest fires are usually viewed in terms of local areas rather than in regional perspectives because of differences between areas in such fire essentials as fuel, weather, climate, and land use. This is accentuated by nonuniformity in State fire enforcement and protection policies as well as by differences in land ownership, both of which contribute to a lack of homogeneity among the social and administrative forces that foster a local perspective.

However, there are many similarities in forest fire activity and behavior or, at least, transitional patterns between areas--both spatially and temporally--that become apparent regionally. The objective of this

paper is to visually display and describe in an atlas format these similarities or patterns using various measures of forest fire activity. Its contents might be useful to fire planners in the establishment of fire seasons and the prediction of peak activity periods as well as provide them with a seasonal guide for allocating fire fighting resources regionally and inter-regionally.

## DATA SOURCE

This atlas is based on 10 years (1960-1969) of reports from the National Forests in the northeastern and north central States (fig. 1) that have uniform reporting procedures. Report forms used by State protec-



Figure 1.--National Forests in the northeastern United States. The Wayne-Hoosier and the Huron-Manistee are combined protection units.

tion agencies are not uniform; therefore, their records were not included.

Geographically, obviously, representation in our data is best in those sections where these Forests are concentrated, for instance, in the Upper Midwest. It is poorest along the eastern seaboard where only two National Forests are located. For some measures of fire activity, either the size of the sample or the reliability of the data posed problems. During this 10-year period, for example, there were only 65 fires reported on the Green Mountain National Forest and 69 on the White Mountain National Forest. Such numbers are simply too small to produce representative frequency distributions.

Our data are generally reliable except for two measures of fire activity--man-hours-to-control and fire cause. These might be questionable because of inaccuracies introduced by flaws in the design of the reporting forms as well as by differences in judgment among those filing the reports. However, the fire-activity data derived permitted statistical comparisons that provide an interpretive base for fire planning.

In an earlier report (Haines *et al.* 1973), we documented the difficulty inherent in comparing fire activity between protection areas. In this report, we account for differences in size of protected areas within each National Forest as well as for variations in numbers of fires and acreage burned (tables 1 and 2) by compiling much of the activity relative to the specific Forest.

Our data are presented as percents of total activity on each forest protection unit, or as percents of peak class. Using this "peak class" method, a value of 100 percent is assigned to the week of the year in which most fires occurred, and this value is used to calculate percentile values for the remaining weeks. This essentially normalizes the individual forest data and partially eliminates the problem of attempting to statistically compare fire activity in different protection areas when using an absolute number scale.

Not all of our summaries will be applicable to specific areas. Each fire manager must judge the similarities and differences between his area and nearby National Forests.

Table 1.--Average annual fire activity on National Forests in the northeastern and north central States during the period 1960-1969.

Protection Unit	Size of protected area <sup>1</sup>	Fires	Area burned	Fires $\geq 10$ acres	Fire days <sup>2</sup>
	Thousand acres	Number	Acres	Number	Number
Allegheny	489.4	10	66	2	8.5
Chequamegon	863.6	10	45	1	9.0
Chippewa	1,246.5	39	404	5	25.1
Clark	1,537.1	212	2,677	34	97.3
Green Mountain	379.0	7	14	<1	6.0
Hiawatha (East) <sup>3</sup>	1,189.1	12	39	1	8.4
Hiawatha (West) <sup>3</sup>	1,189.1	18	87	1	15.1
Huron <sup>3</sup>	1,750.6	23	323	3	25.1
Manistee <sup>3</sup>	1,750.6	87	339	6	49.8
Mark Twain	1,005.7	140	1,557	24	74.3
Monongahela	1,191.4	22	179	3	18.1
Nicolet	941.7	23	148	2	17.5
Ottawa	1,223.4	16	63	1	12.9
Shawnee	490.6	41	524	10	29.0
Superior	2,722.0	60	300	3	40.2
Wayne <sup>3</sup>	532.4	82	430	10	42.0
Hoosier <sup>3</sup>	532.4	29	502	8	22.2
White Mountain	788.1	7	13	<1	5.9

<sup>1</sup>1969 total protected acreage.

<sup>2</sup>A day having at least one reported fire.

<sup>3</sup>Combined as a single unit.

Table 2.--Fire activity on National Forests in northeastern and north central States during the period 1960-1969

Protection Unit	Peak seasons		Total activity within peak activity seasons										Maximum fires/day	
	Spring	Fall	No. of fires	Burned acreage	Man-hours to control	Fire acres: $\geq 10$ acres	Fire days <sup>1</sup>	Damages	In season	Out of season				
						Percent				Number				
Allegheny	3/19-5/27	9/24-12/9	87	84	63	88	86	87	3	2				
Chequamegon	3/26-6/10	10/1-12/2	76	83	58	80	73	75	4	2				
Chippewa	3/12-7/1	10/8-11/18	86	98	96	98	83	86	8	4				
Clark	2/5-5/13	10/8-12/9	82	91	96	85	71	81	23	9				
Green Mountain	4/9-11/25 <sup>2</sup>		100 <sup>3</sup>	100	100	100	100	100	3	0				
Hiawatha (East) <sup>4</sup>	4/2-10/28 <sup>2</sup>		96	81	100	74	96	96	9	5				
Hiawatha (West) <sup>4</sup>														
Huron <sup>4</sup>														
Manistee <sup>4</sup>	3/26-9/2	10/1-10/28	93	92	94	94	91	93	12	6				
Mark Twain	1/8-5/13	10/22-12/9	84	92	92	90	75	83	16	4				
Monongahela	3/12-7/29	10/1-12/9	97	99	97	100	96	97	5	1				
Nicolet	4/2-7/29	10/8-10/28	84	93	84	89	82	84	5	3				
Ottawa	4/9-8/26	10/1-10/28	94	100	100	100	93	94	4	2				
Shawnee	2/12-5/6	10/1-12/9	84	89	92	87	80	85	7	2				
Superior	4/2-11/4 <sup>2</sup>		99	99	100	97	99	99	6	1				
Wayne <sup>4</sup>														
Hoosier <sup>4</sup>	1/22-5/13	10/8-12/9	93	96	92	96	89	93	10	4				
White Mountain	4/30-10/21 <sup>2</sup>		100 <sup>3</sup>	100	100	100	100	100	3	0				

<sup>1</sup>A day having at least one reported fire.

<sup>2</sup>Only one peak season.

<sup>3</sup>The small number of fires caused statistical distortion in defining seasons.

<sup>4</sup>Combined as a single unit.

## VEGETATIVE COVER

Within the northeast and north central States, forest ground cover varies dramatically from large expanses of grassland to heavy conifer stands to rolling hills of hardwoods (Kuehler 1964, Braun 1950). The USDA Forest Service (1960) handbook lists 38 different fuel classification types on their fire reports that we grouped as follows: grass, conifer, hardwood, and other (usually slash or brush).

Over 50 percent of the fires reported in the northeastern and north central States burned in hardwood stands (fig. 2). These fires dominate in the lower Midwest and East which reflects the prevailing cover type in these areas. Grass fires are predominant through the upper Midwest, except in northeastern Minnesota where conifer fires dominate. However, conifer fires do account for a significant number of fires in other areas.

In terms of burned acreage (fig. 3), a somewhat different pattern emerges: for hardwood fuels, the percents in figure 3 are generally lower than the percents in figure 2; for grass fires, the percents are generally higher in figure 3 than those in figure 2. This can be attributed to the suppression techniques and the burning characteristics of grass fuels (especially high spread rates) which makes it difficult to limit grass fires to small areas.

We found the "average size" of grass fires to be large, for example, 6 acres on the Ottawa National Forest, 10 acres on the Superior National Forest, and 16 acres on the Chippewa National Forest. However, as a statistical measure, "average" is a poor description of fire size. One or two unusually large fires can distort such averages, especially when fire incidence is low.

The median is a better statistical reference (fig. 4). When we computed this term, we found that medians for grass fires were under  $\frac{1}{2}$  acre for the Ottawa National Forest, about 1 acre for the Superior National Forest, and 2 acres for the Chippewa National Forest.

In Missouri, Illinois, and Indiana, where slash-brush complexes are of special concern, the medians range as high as 4 or 5 acres as compared to averages that range as high as 24 acres. Medians are lowest on the Green

Mountain National Forest and on the White Mountain National Forest where total fire numbers also are low.

The flammability of a fine fuel complex is influenced by the proportion of living to dead materials. Consequently, the phenological stage of herbaceous plants has become an integral part of fire danger rating systems. We used the three broad stages described by Nelson (1964) in which vegetation is considered as follows: (1) *cured* when a visual survey indicates that 75 percent or more is dead or dormant, (2) *transition* when 25 to 75 percent is dead or dormant, and (3) *green* when less than 25 percent is dead or dormant.

Figure 5 gives the median spring and fall week in which these stages occur. These median dates can only be viewed as approximations because of the relatively short period record and the limited number of observation stations.

Vegetation changes from the cured stage to the transition stage in late April in the southern forests and about a month later in northern forests (fig. 5A). When viewed broadly, this spring transition stage appears largely latitude dependent; if more detail were available, the isolines would present a more complex pattern, especially in mountain ranges. One to 3 weeks are usually required for living vegetation to move from the transition stage to the green stage (fig. 5B). The south to north "greening-up" pattern in figure 5A is also evident in figure 5B.

In autumn, a more complex, reverse pattern appears. In the north, vegetation moves into the transition stage by mid- to late September, which means that vegetation is in the green stage an average of 18 weeks (fig. 5C). The north to south curing trend in the fall is not as pronounced as the "greening-up" pattern in the spring. For example, vegetation in southern Ohio and West Virginia shows some of the temporal curing characteristics of vegetation in the northern tier of forests. However, vegetation in southern Missouri, Illinois, and Indiana doesn't reach the transition stage until mid-October, which means that it is in green stage an average of 25 weeks

This annual vegetative cycle is completed with a return to cured condition in the north by mid-October and in the

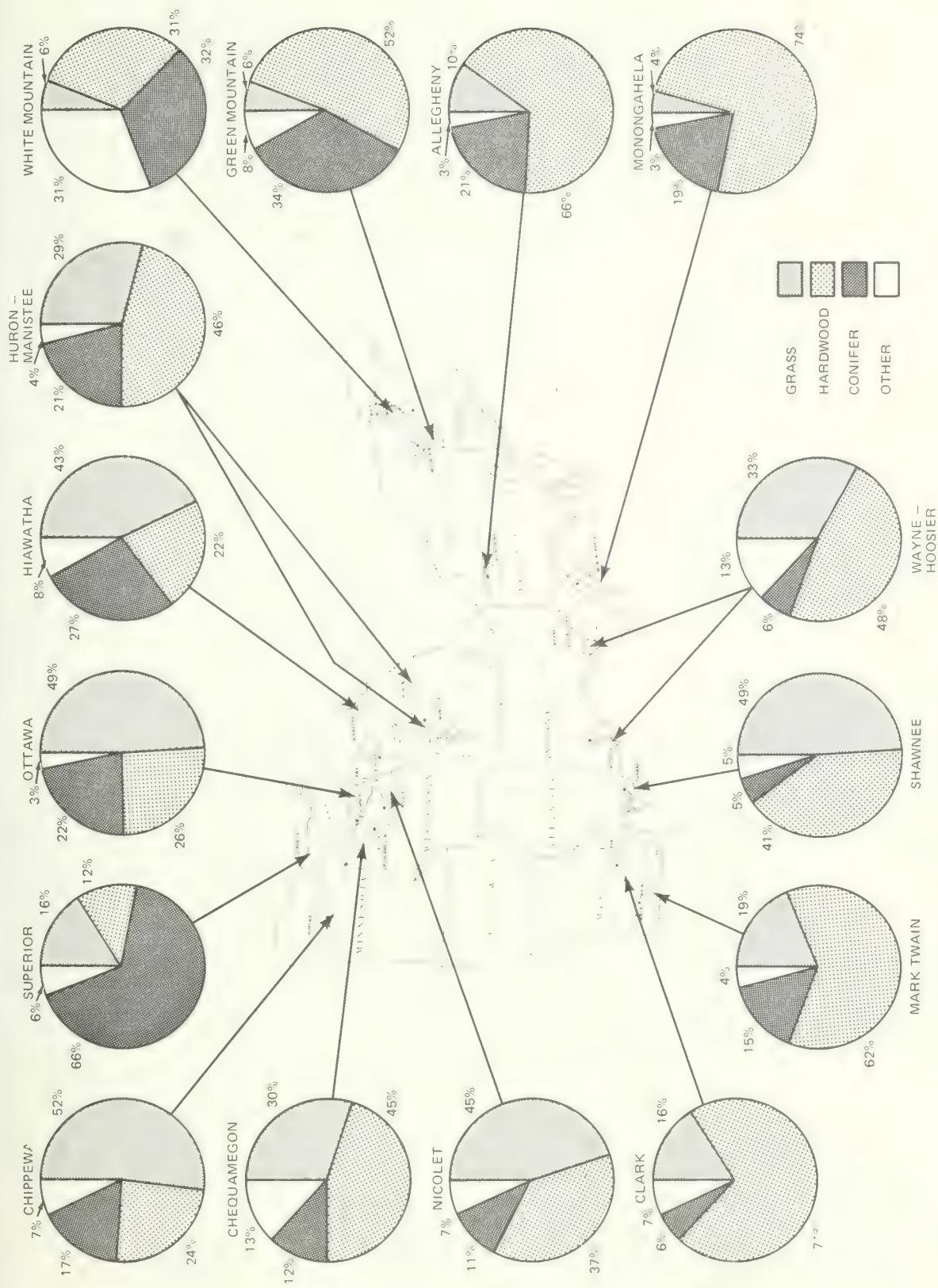
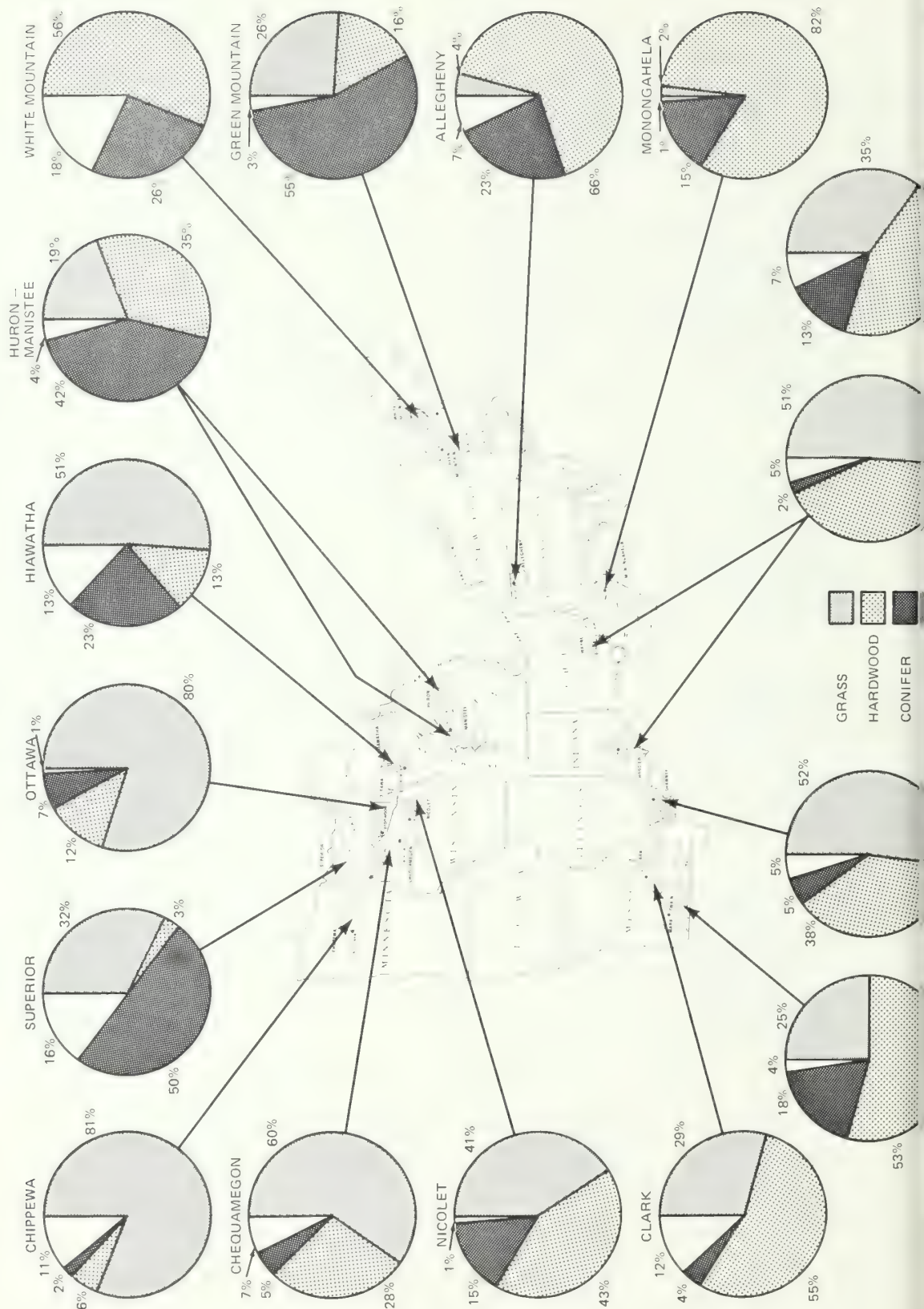
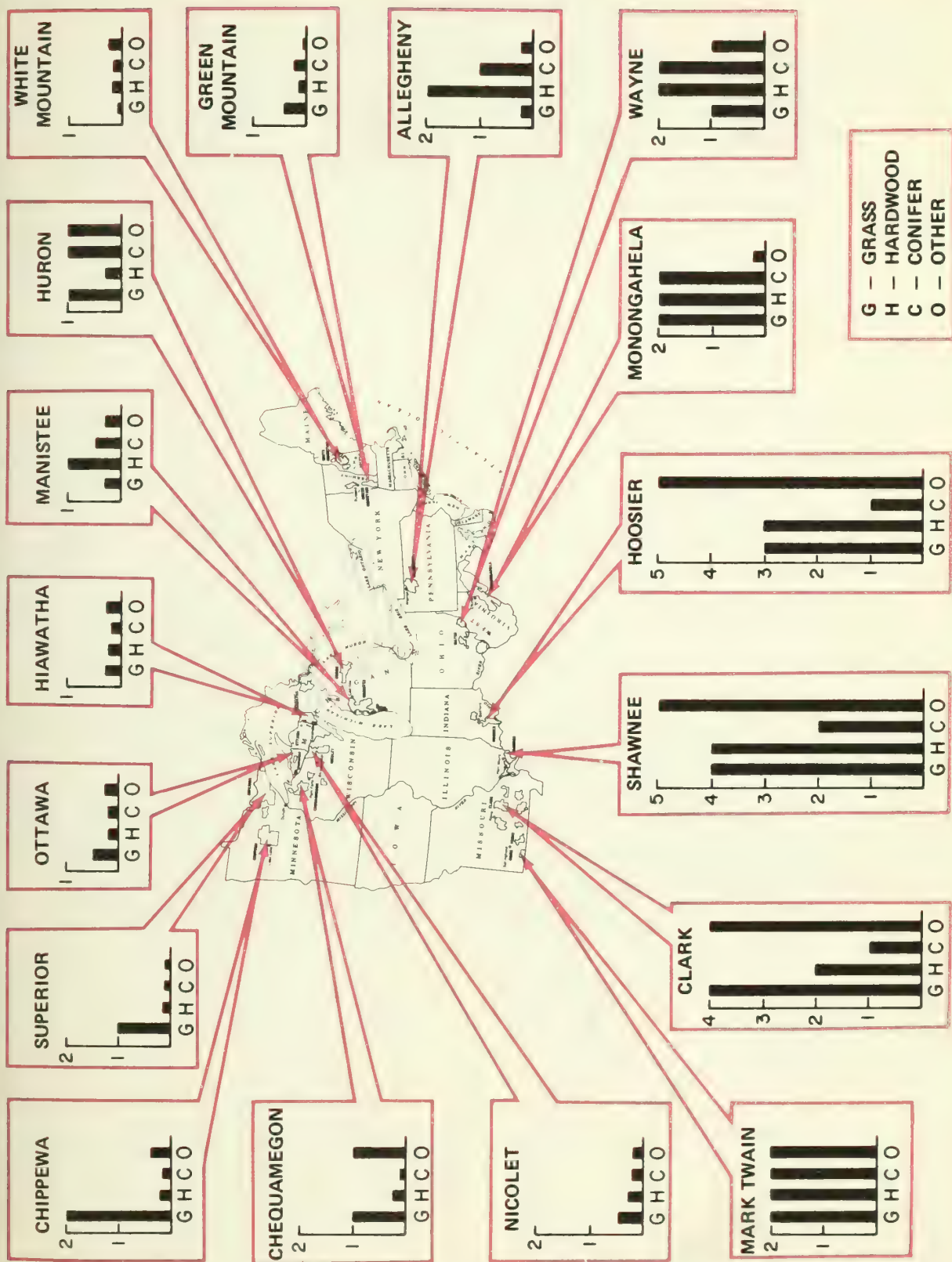


Figure 3.--Percent of burned acreage in four prevailing cover types.





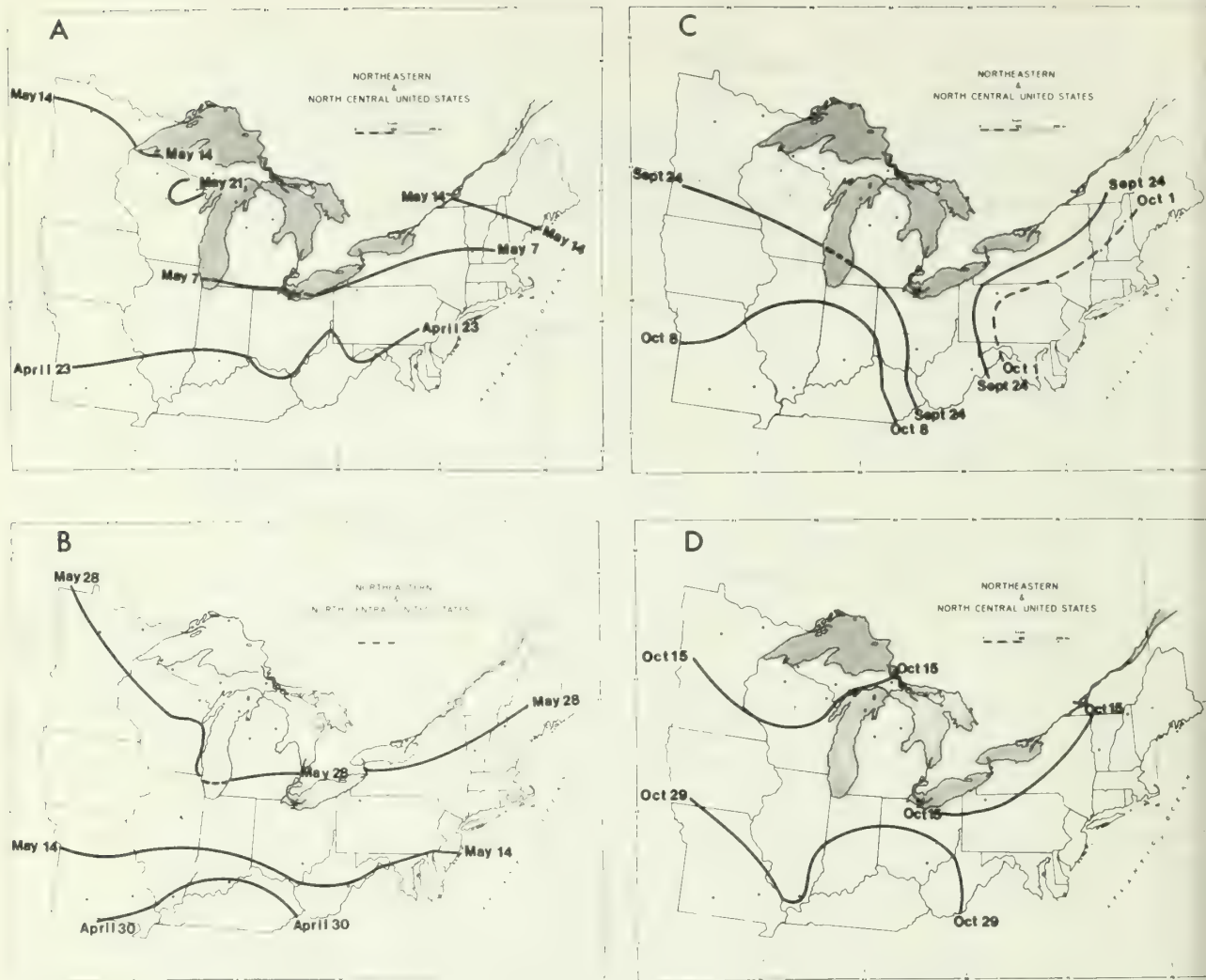


Figure 5.--A. Median spring week when vegetation stage changes from cured to transition. B. Median week when vegetation stage changes from transition to green. C. Median fall week when vegetation stage changes from green to transition. D. Median week when vegetation stage changes from transition to cured.

south by early November (fig. 5D). The lengths of time in this transition stage vary widely but are generally longer in the autumn than in the spring; the median periods range up to 7 weeks in some areas. This factor is reflected in the isoline pattern for the autumn.

The relation of this phenological cycle to fire occurrence is portrayed in figure 6 for the Mark Twain National Forest. The pattern is typical of northeastern forests

that have well-defined spring and fall fire seasons. Vegetation is in the cured stage during the peak period of the spring season. Fire occurrence drops rapidly as vegetation enters the transitional stage. There is little fire activity during the summer because of the lush vegetation. In the fall, fire activity increases as the vegetation enters the transitional stage; it usually peaks shortly after the vegetation enters the cured stage and then declines with the advent of winter conditions.

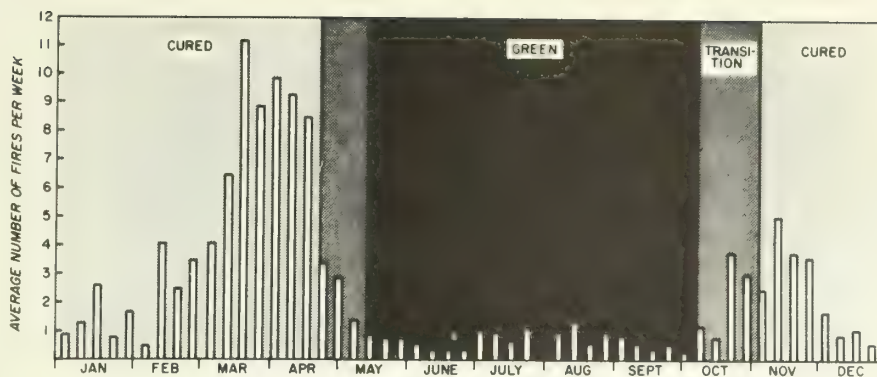


Figure 6.--Average number of fires per week and seasonal vegetative stages on the Mark Twain National Forest.

### NUMBERS-OF-FIRES PROFILES

Three distribution forms are evidenced in figure 7: (1) symmetrical, (2) skewed, and (3) bimodal.

The *symmetrical* form is typified by the profile for the Superior National Forest. In general, fire numbers increase from spring until mid-year, then decrease until fall.

The *skewed* form is typified by the profiles for the Nicolet and the Ottawa National Forests. On these Forests, fire activity is dominant during the spring but distribution is erratic during the summer and fall.

The *bimodal* form is typified by the profiles for the National Forests in the southern tier of States. Fire activity peaks in both spring and fall. Spring activity ceases as vegetation begins the transition to the green stage and increases as the vegetation begins to cure in the fall (fig. 6). This phenomenon is amplified in hardwood forests during the summer months by the leafy canopies that reduce solar radiation at the forest floor, while permitting moisture to build up in the fuels.

In the profiles for the southern tier of forests there is a noteworthy west to east march toward progressively stronger, fall fire activity. For example, the profile for the Mark Twain National Forest displays an intense activity season in the spring and a much weaker activity season in the fall; 66 percent of the fires occurred in the spring season, 22 percent in the fall.

On the Monongahela National Forest, however, only 38 percent of the fires occurred in the spring, 46 percent in the fall. This difference might be attributed to the drought that occurred in the eastern States during the early 1960's. It caused early fall curing of vegetation, which could well have extended the fall activity season in some areas. This drought might also be reflected by the spring-fall differences in the herbaceous stages in figure 5.

The drought began in areas of the Northeast during September 1961, developed extreme characteristics by the end of September 1964, and spread southward during 1965 (National Oceanic and Atmospheric Administration 1965). By the end of 1965, the drought was extreme in northern West Virginia, northern and eastern Virginia, Maryland, Delaware, New Jersey, eastern Pennsylvania, southwestern New York, and central and southern New England. In most of these areas, this severity persisted through the summer of 1966 but gradually diminished when widespread rainfall occurred in September and October of 1966. By the end of October, the drought was limited to south central Pennsylvania and smaller, isolated areas in the Northeast (National Oceanic and Atmospheric Administration 1966).

In the Eastern Ozarks, however, the drought remained mild to moderate during the period 1962-1965 (Haines *et al.* 1973). During 1963-1966, fires increased 20 percent on the Mark Twain National Forest, about 33 percent on the Clark and Shawnee, 50 percent on the Monongahela, and 90 percent on the

Wayne-Hoosier, as compared to the totals for 1960-1962 and 1967-1969 (table 3). However, these increases were not distributed proportionally throughout the entire year.

During the spring season, the annual percentage of fires was lower during the drought years throughout the entire southern tier of States. During the fall season, however, the annual percentages of fires were as much as 17 percent higher during the drought period on some forests.

Obviously, these figures do not fully support the hypothesis that drought caused the west to east march toward progressively stronger fall fire activity. In most areas drought appears to be the cause, but not in West Virginia where the percents of fall fires during the drought years matches the percents during nondrought years. We might be able to attribute this to the fact that we only had data for the one National Forest in West Virginia, which averaged 22 fires per year.

Data from State Forests in West Virginia support the hypothesis that drought was the cause here also. There was much more fire activity during the spring seasons than during the fall seasons on these State Forests, except during 1964 and 1965 when the drought was most severe.<sup>1</sup>

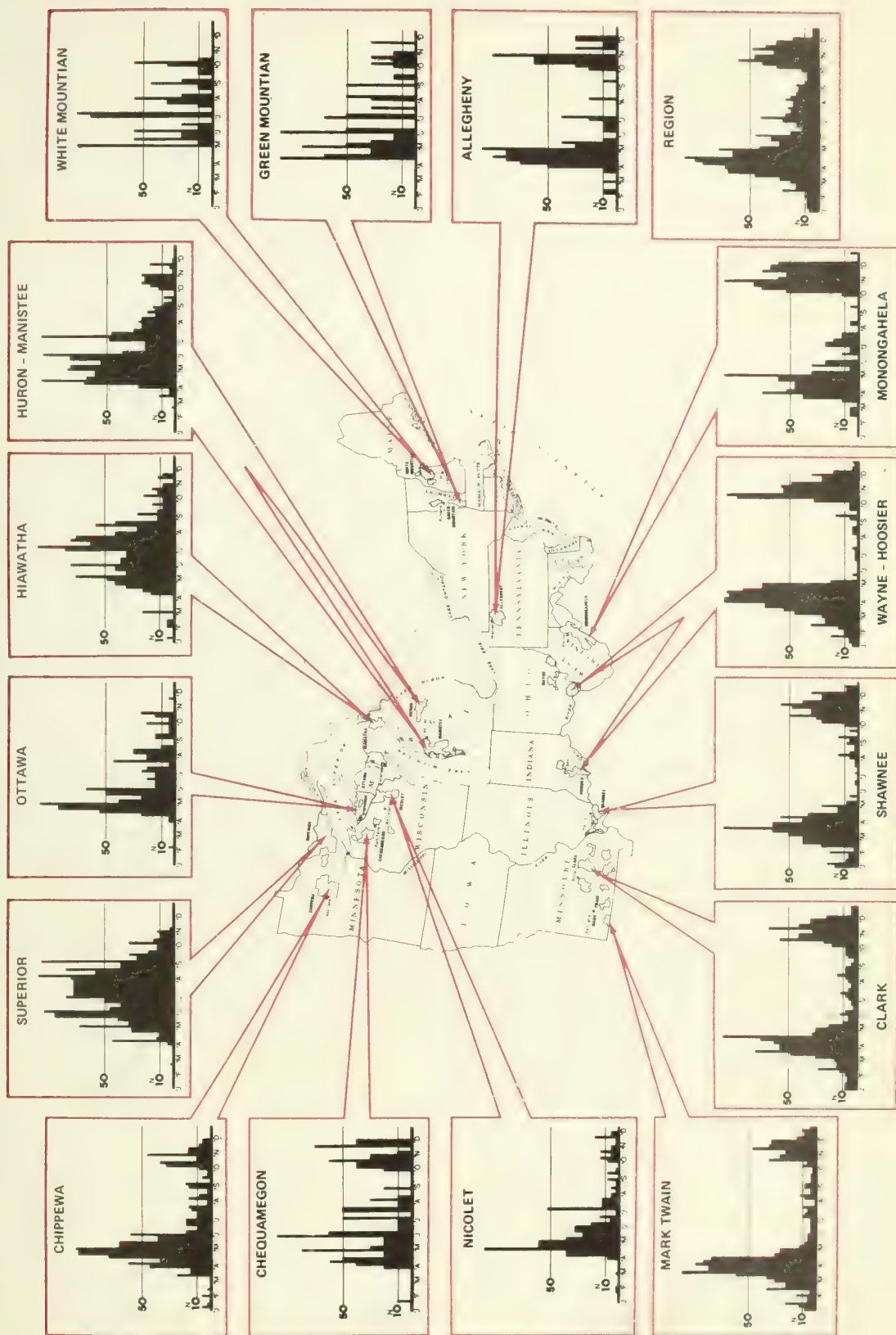
Another possible factor in this west to east shift may be differing social attitudes through the southern sector. In Missouri, for example, spring is customarily a favored time for burning woods (Haines *et al.* 1973). In Missouri, furthermore, debris burning and incendiaryism have been traditional causes of wildfires. In West Virginia, the same social factors are predominant, but not to the same degree, nor as concentrated in the same seasonal pattern as in Missouri.

<sup>1</sup>Personal correspondence with Asker W. Kelly, Jr., West Virginia Department of National Resources, 1973.

Table 3.--Annual fires that occurred in spring fire activity and in fall fire activity seasons during drought years (1963-1966) and nondrought years (1960-1962; 1967-1969) on National Forests in the north central and northeastern States

Forest	Spring season		Fall season		Yearly average	
	Drought : Nondrought		Drought : Nondrought		Drought : Nondrought	
	years	years	years	years	years	years
	Percent					
	-		-		-	
Mark Twain	65	67	18	17	155	129
Clark	50	53	32	29	249	186
Shawnee	40	66	40	23	48	36
Wayne-Hoosier	52	71	40	24	155	81
Monongahela	47	51	47	47	28	19

Figure 7.--Distribution of numbers of fires expressed as a percent of the peak class (by week). See page 2.

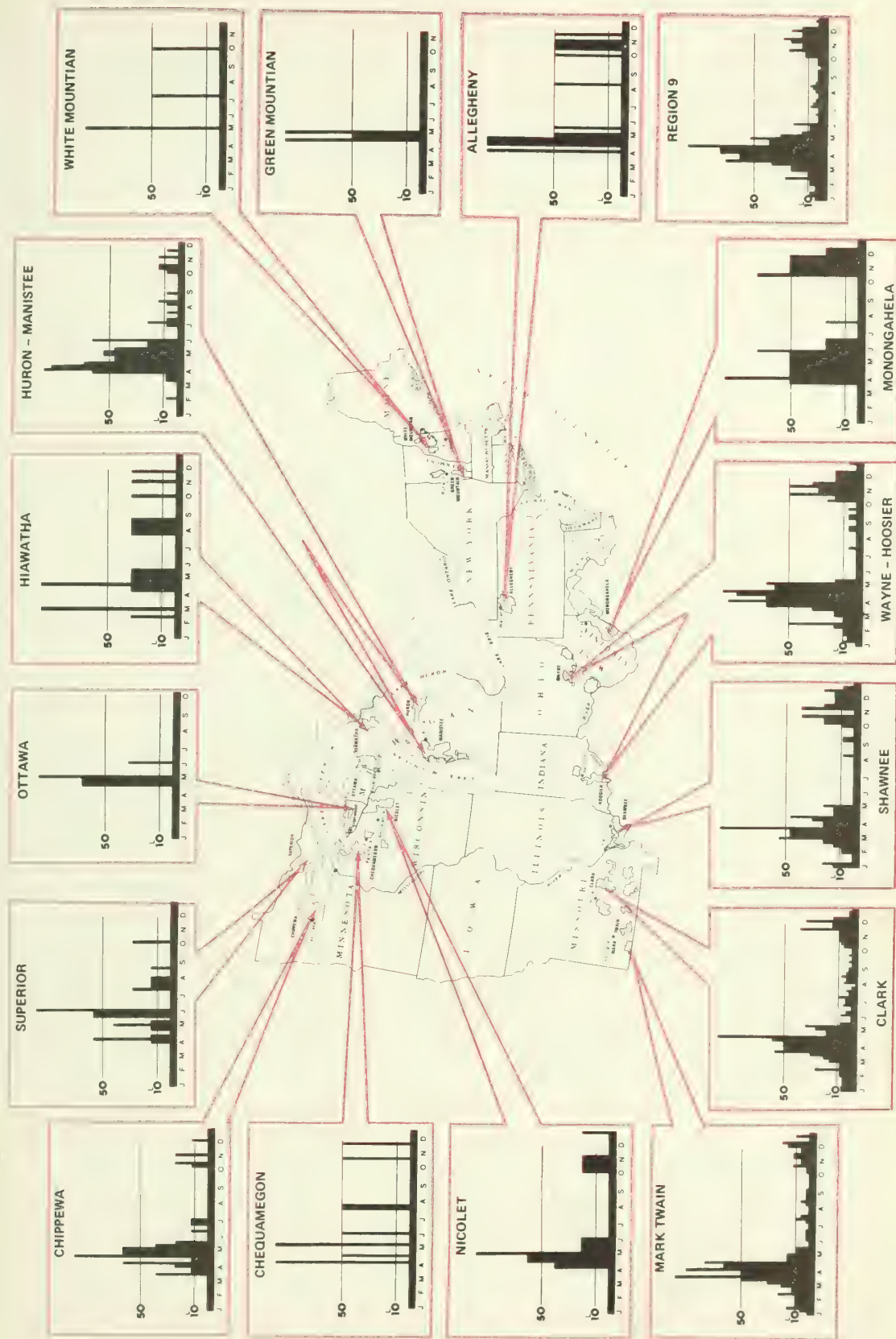


## NUMBERS OF FIRES $\geq$ 10 ACRES PROFILES

Profiles of fire numbers alone as shown in figure 7 do not present the complete wild-fire story. Consequently, we also compiled profiles for numbers of fires  $\geq$  10 acres (fig. 8), burned acreage (fig. 9), and man-hours-to-control (fig. 10). These profiles are erratic because we did not have sufficient data from most forests, but we can still draw meaningful information from them.

They indicate that large fires ( $\geq$  10 acres) are more of a spring season phenomena than are total fires. This appears contradictory considering that the major drought of the 1960's caused a higher percent of total fires during the fall season than during the spring. Historically, the great fires of the Region have occurred in the fall, usually following record droughts (Haines and Sando 1969).

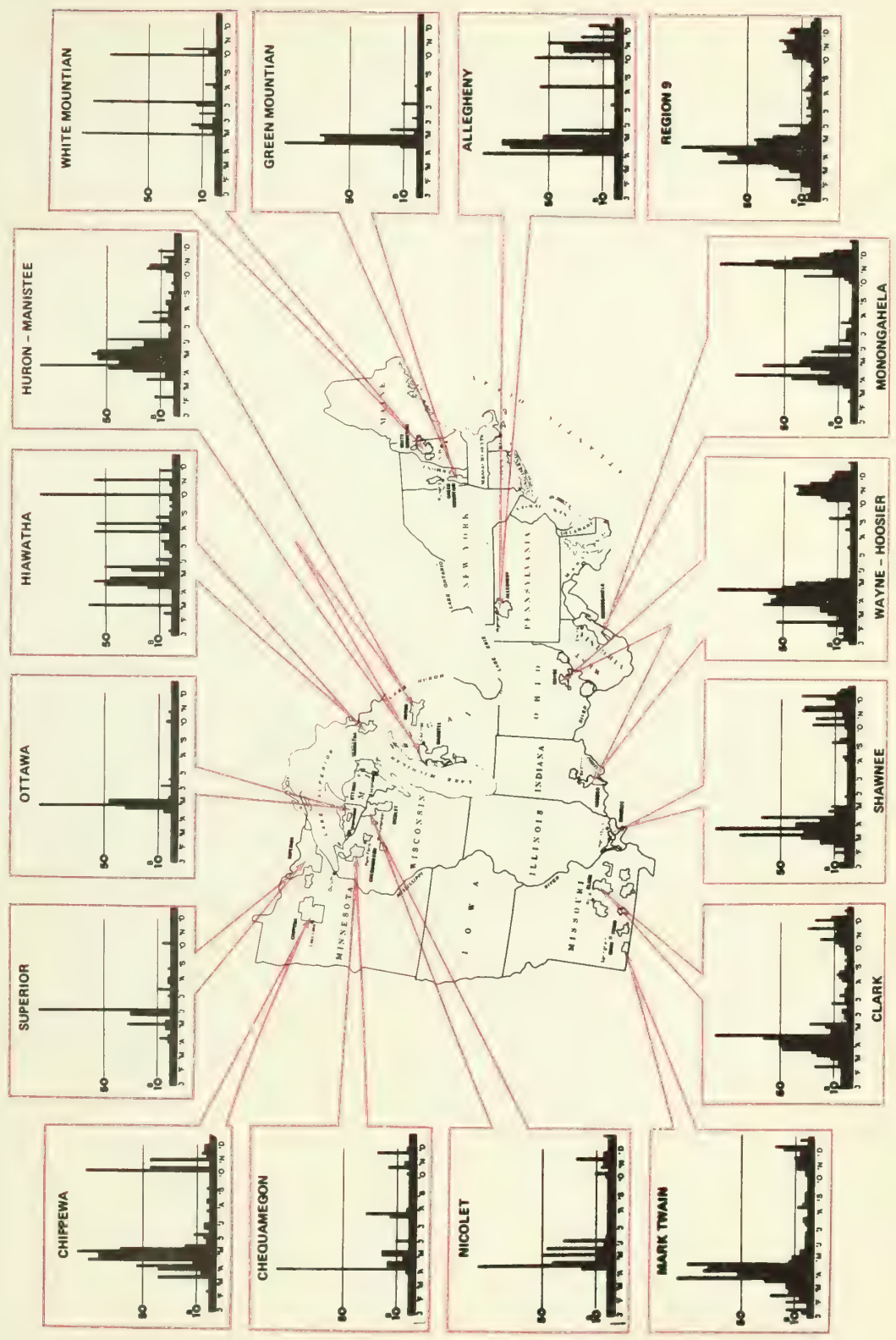
Figure 10. Distribution of ...



### ACREAGE BURNED PROFILES

The profiles shown in figure 9 indicate that the greatest acreage is also burned in the spring. Most of the forests having a moderate number of summer fires have low summer burned acreage which indicates, as do the profiles in figure 8, that there is little real danger of catastrophic fires during the summer season. During the summer, green vegetation acts as a heat sink; this keeps a fire's propagation-intensity rate low. Furthermore, higher humidities and low windspeeds near the ground also modify microclimate conditions during the summer.

the peak class (by week). See page 2. Individual fires of over 300 acres were assigned that value in order to balance the profiles.

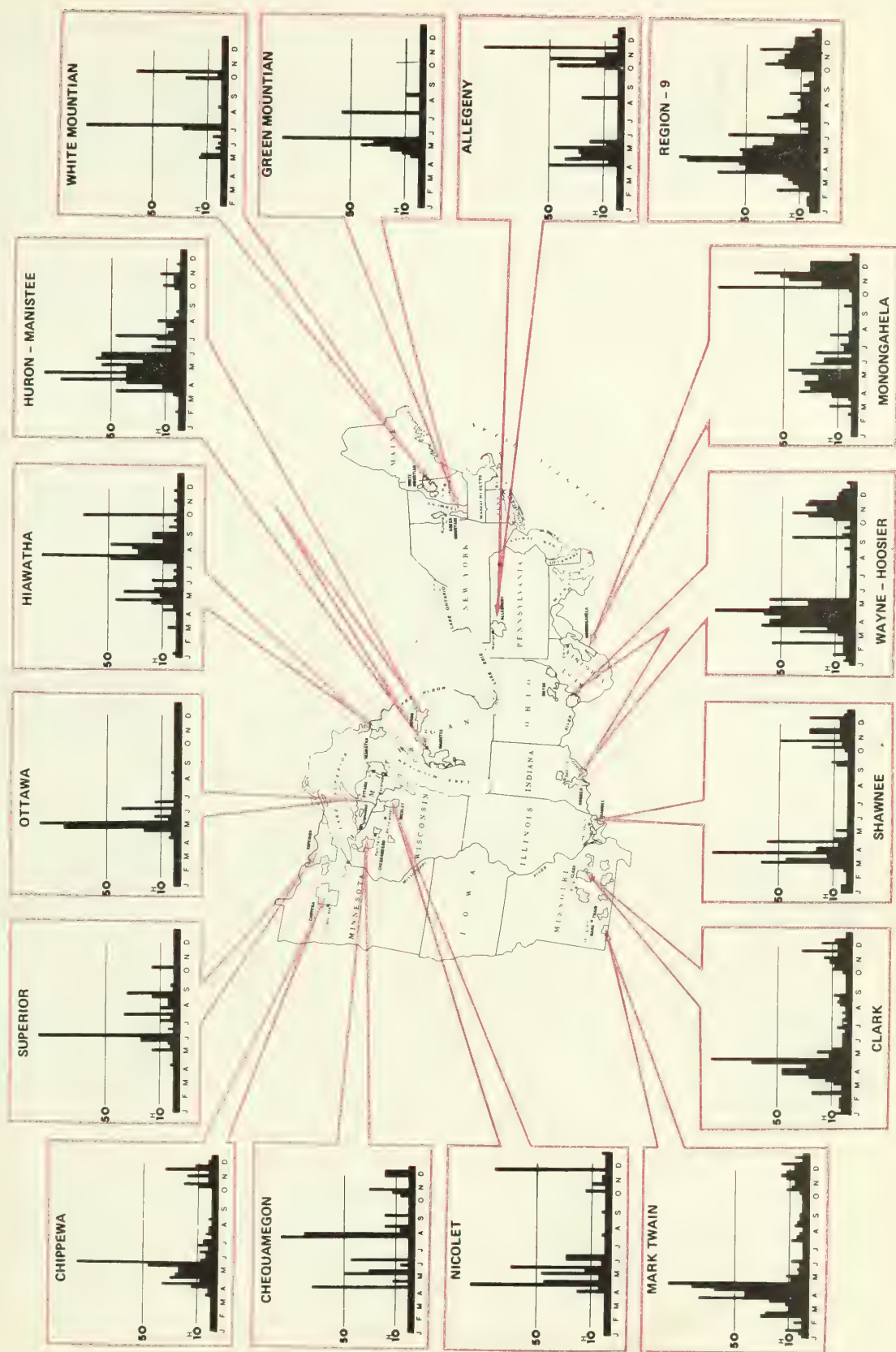


## MAN-HOURS-TO-CONTROL PROFILES

The profiles for man-hours-to-control (fig. 10) have a somewhat lower reliability factor than the profiles for numbers of fires, burned acreage, or large fires. Availability of the fire fighting resource may be a manager's prime Manning consideration, although he also may have any number of other reasons for sending a given number of men or equipment to a fire. It isn't possible to pinpoint fires that were over-manned from the records.

The profiles for man-hours-to-control do not always conform to the profiles for burned acreage and large fires. For the Hiawatha National Forest, for example, the greatest number of man-hours occurs in July and August along with peak fire numbers. For the Mark Twain and the Clark National Forests, man-hour profiles are aligned more closely with large fire and burned acreage activity. Specific reasons for these variations are not clear. Perhaps it indicates that some units, such as the Hiawatha National Forest, concentrate their resources upon initial attack because large fires are not normally a problem on that Forest (table 1 and fig. 4).

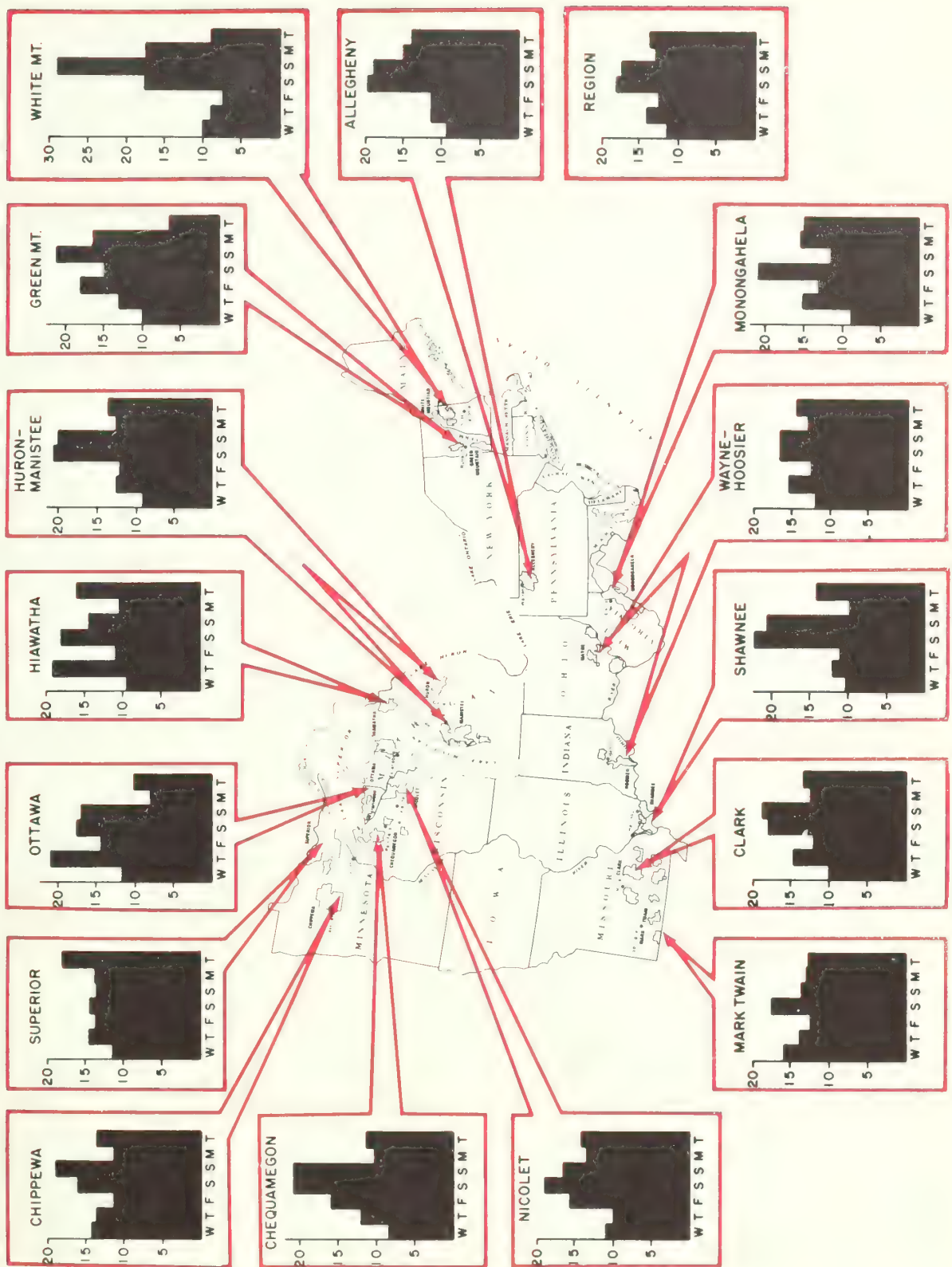
of the peak class (by week). See page 2. Individual fires of over profiles.



#### DAY-OF-WEEK PROFILES

Haines *et al.* (1973) reported that forest use is one of the most critical influences on day-of-week fire numbers--perhaps the most crucial. They showed that heavy recreational activity produced an increase in weekend fires on the Clark National Forest, although there were no such increases on nearby State Forests in Missouri, where other uses dominated. These findings are reflected in the profiles shown in figure 11. Managers should be alert to other day-of-week patterns as they relate to fire cause.

Figure 11. Percent of jobs narrowed by day of week, near region on Wednesday, thereby keeping weekend drive in a region



## FIRE CAUSE

Most tabulations of fire-cause data are extremely limited in scope. From these tabulations, one can recognize the number of lightning fire starts vs. those caused by human activity, but further detail often is sparse. Categorization generally follows some sequence identifying people or their activity. Deriving information from such categories is difficult because it is almost impossible to devise a simple one- or two-word designator that fully describes activities coupled with the parties responsible.

Main and Haines (1973) attempted to increase the amount of meaningful information

in fire-cause tabulations by cross indexing various classes of people and their activities. This method produced the more specific fire-cause combinations shown in figure 12. The percent of total fire starts accounted for by the listed combinations is given in the hubs.

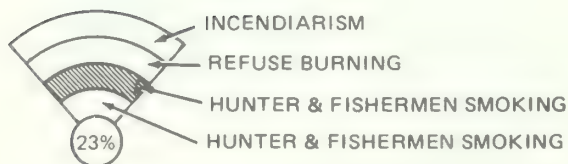
On most National Forests, any one cause combination accounted for less than 5 or 6 percent of the total. However, some units showed as much as 20 to 25 percent or more of their activity in a single combination. Only the dominant combinations were included in figure 12.

The combinations produced some recurring patterns. For example, in Missouri,

Figure 12.--Fire cause by class of people and activity. The more dominant the cause combination, the further its position from the center of the hubs. The percent of total fire starts accounted for by the listed combinations is given in these hubs.

## LAKE STATES

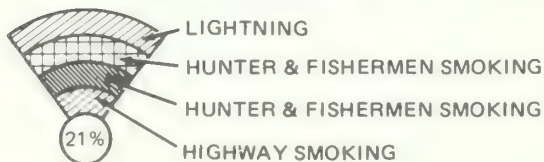
### CHIPPEWA



### SUPERIOR



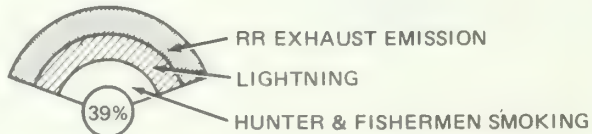
### CHEQUAMEGON



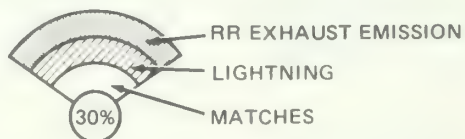
### NICOLET



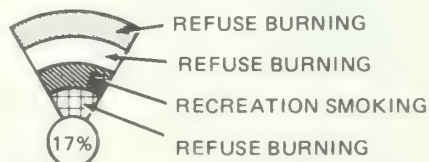
### OTTAWA



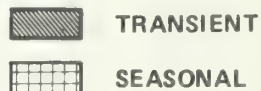
### HIAWATHA



### HURON-MANISTEE



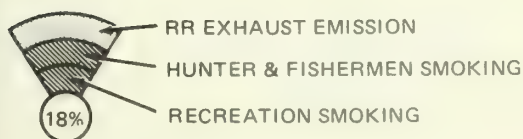
## LEGEND:



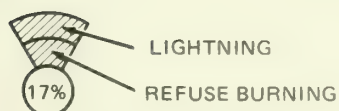
Indiana, and Ohio, one recurring combination is incendiarism (pyromania). However, pyromania is an unfortunate classification label because it implies that the investigator is competent to make medical judgments. This inappropriate type of reporting results from application of the term "incendiarist," which is among the confusing terminology required in the standard format in fire report forms.

Main and Haines (1973) show that fire cause is a diversified problem. Local incendiarism is the most pressing prevention riddle. They conclude that prevention efforts might well be concentrated on groups that are both highly identifiable and relatively cohesive, such as hunters and fishermen who are licensed. Their data indicate hunters and fishermen represented more of a fire problem during the period of their study than all other combinations of recreationists. Moreover, their study also identified local people as the primary group responsible for fires.

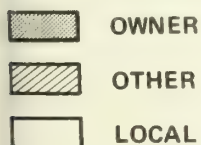
## EASTERN STATES ALLEGHENY



## GREEN MOUNTAIN

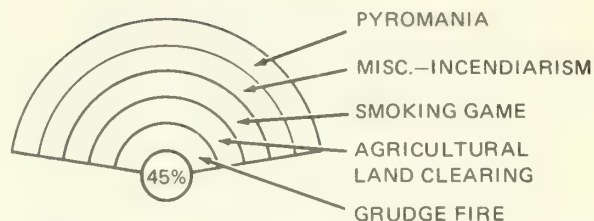


## WHITE MOUNTAIN

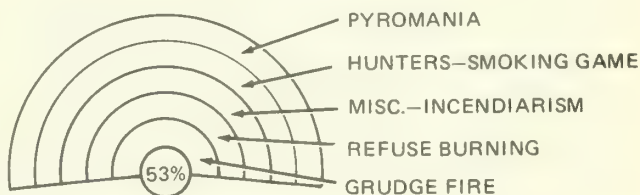


## SOUTHERN TIER STATES

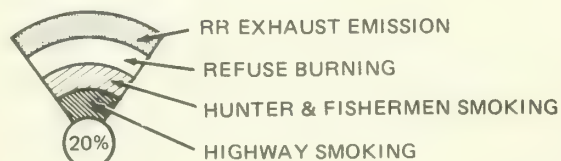
### MARK TWAIN



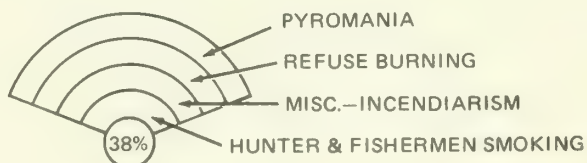
### CLARK



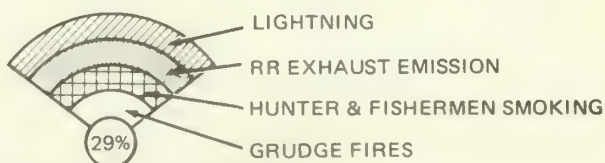
### SHAWNEE



### WAYNE-HOOSIER



### MONONGAHELA



## PEAK ACTIVITY SEASONS

The term "fire season" might be interpreted in a number of ways. For example, in the USDA Forest Service Glossary (1956), it is defined as, "the period or periods of the year during which fires are likely to occur, spread, and do sufficient damage to warrant organized fire control." However, interpreting what is meant by terms such as "likely" or "damage" poses problems.

Some organizations arbitrarily select a specific date in the spring to start their fire season and end it after the first good snowfall in the fall. Some fire seasons are fixed by legislative decree. Other organizations base their season on various past records. For example, an arbitrary percentage of total fires might be included to define the calendar date limits of the season; 90 percent is currently being used as a planning base in many USDA Forest Service Regions.

Obviously, a fire season is determined to a large degree by operational concerns. Therefore, we attempted a somewhat different conceptual term "peak activity season." Our profiles, especially the profile tabulated from numbers-of-fires data (fig. 7), are based on such seasons. A peak activity season begins during the week fires total 10 percent of the number of fires expected for the worst week of the year. Seasons end on the same basis. When the number of fires drop below 10 percent of the amount experienced during the worst week, a season is over.

It is easiest to establish peak activity seasons for forests having many fires, such as those in Missouri. It is more difficult for forests having few fires, such as those in the New England States, where the peak activity seasons we defined begin when the first fire is reported and end when the last fire is reported (table 2).

In operational usage, the peak-activity-season designation might be modified by considering other factors. It's obvious, for example, that fires occurring in early spring or late fall sometimes do minimal damage because of seasonal weather, fuel, or soil conditions. Therefore, we examined the percent of other measures of fire activity that occurred within the peak activity seasons (table 2). In 12 of the 15 protection units, the percent of annual burned

acreage was equal to or greater than the percent of total fires within these seasons. This also applies to another measure of activity--number of man-hours-to-control. Furthermore, 13 of the 15 protection units had at least as great a percent of large fires ( $\geq 10$  acres) as numbers of fires within season. Operationally, therefore, the peak activity seasons shown in table 2 also include an acceptable percent of the other important measures of fire activity.

A plot of the beginning weeks in which fire numbers were  $\geq 10$  percent of peak activity produced the map shown in figure 13. There is a northward progression in the spring as snow disappears, temperatures rise, and outdoor activity increases. This progression commences along the southern tier in January, and moves northward during February, March, and into April. This indicates when to begin weather measurements, when to be concerned about fires, and when to be alert to weather systems that produce high fire danger.



Figure 13.--First week in which fire numbers are  $\geq 10$  percent of peak activity week.

We also tabulated the difference in weeks of the seasonal starts based on three other measures of fire activity--large fires, burned acreage, and man-hours to control--from the seasonal starts based upon numbers of fires. This showed that large fires occur at  $\geq 10$  percent of their peak week activity about the same time to 1 week later than the start of the seasons shown in table 2. Seasons based on burned acreage lag about

1 week and seasons based on man-hours-to-control lag an average of 1 to 2 weeks after the seasons shown in table 2.

The spring season (based on fire numbers) peaks in mid-March in the extreme south and sometime in April through most of the rest of the north central and northeastern States (fig. 14). In general, the peak fire period occurs 2 to 3 weeks before the cured-to-transitional change in vegetative stages (fig. 5A). Distributions on the Superior and the Hiawatha National Forests were not included in this analysis because of their symmetrical patterns. Nor did we attempt to continue the isolines through the eastern half of the Region because of our meager data.

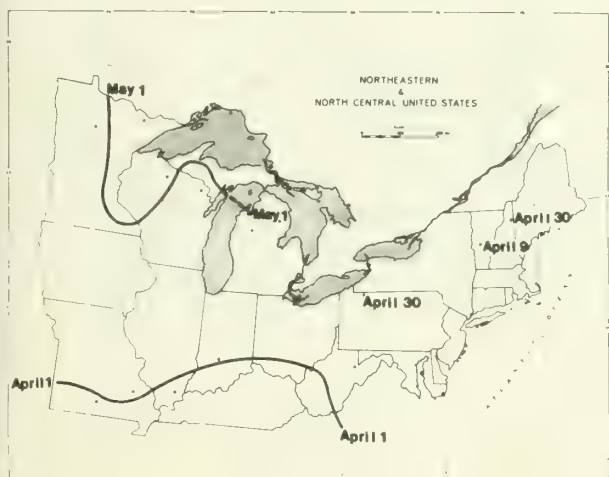


Figure 14.--Week of maximum spring season fire numbers.

The fall activity season ends in late October in the north central Lake States and the extreme Northeast but not until early December through much of the southern tier (fig. 15).

On the average, fires are first reported between 2:15 and 2:30 p.m. in the north central and northeastern States. Two-thirds of the fires were first reported between 11 a.m. and 6:30 p.m. Nine out of 10 fires were first reported between 8 a.m. and 8 p.m. There was little change in these times over the course of the year, although after mid-September, fires do tend to occur a bit earlier in the afternoon.



Figure 15.--Last week in the fall with fire numbers still  $\geq$  10 percent of peak activity.

#### USE OF ATLAS INFORMATION

Figure 16 shows a combined profile of predicted fire danger and reported fire activity for the Clark National Forest. Both are displayed as percents of peak class (see page 2). With the combined profile we can visually gauge the effectiveness of various fire danger rating systems by comparing their predictive features to annual fire activity.

The predictions (Schroeder *et al.* 1964) are based on application for delineated regions throughout the United States of the Wildland Fire Danger Rating System (USDA Forest Service 1962). This application was for the period 1950-1960 and its predictions were based on a Fire Load Index above 16 as separating critical from noncritical fire-danger days.

The data compiled for the observed fire activity (fire-days) also represent the period 1950-1960 with a fire-day defined as a day having at least one fire. The profile generally patterns the profiles derived from the 1960-1969 data for the Clark National Forest (figures 7 to 10). However, it also shows a secondary fire peak in September, which might be attributed to the moderate to extreme drought that affected the area from 1952-1955 (Haines *et al.* 1973).

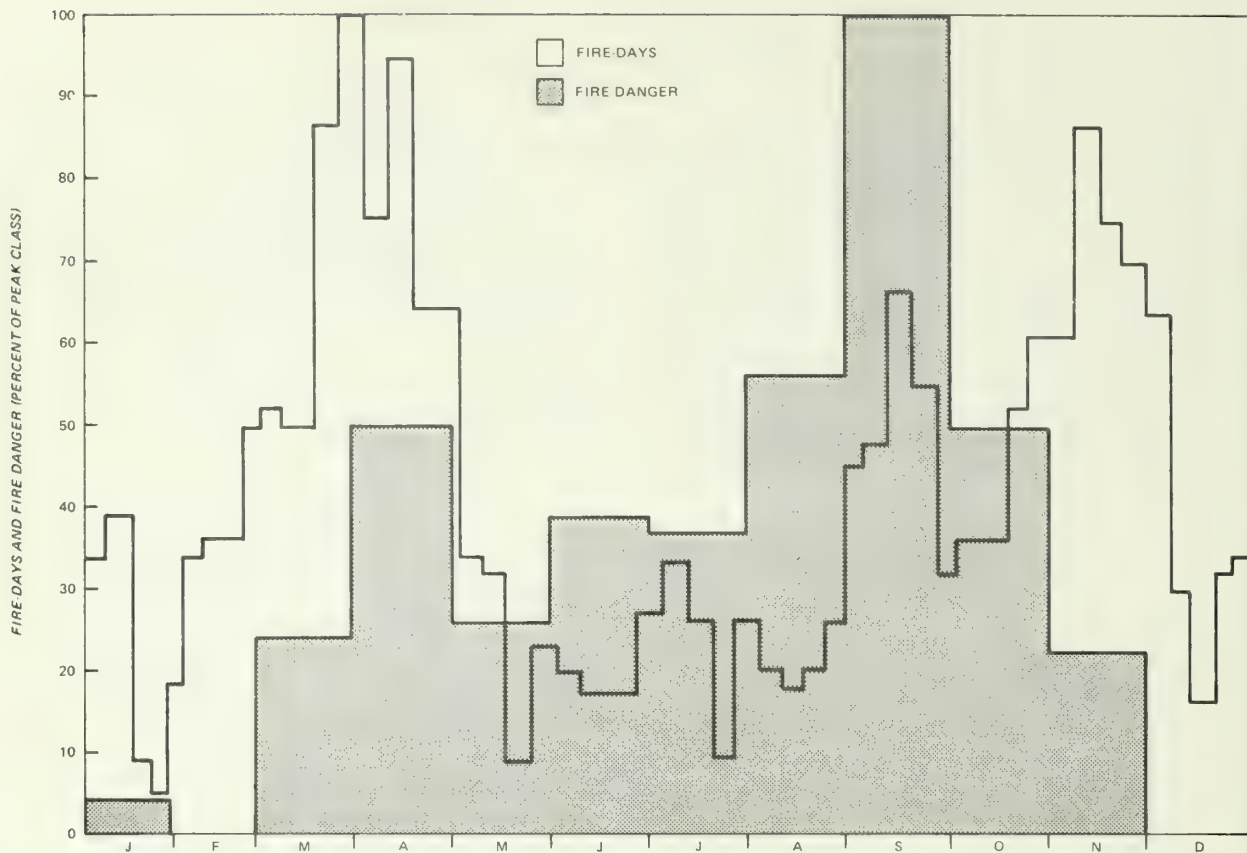


Figure 16.--A comparison of fire-days and fire danger for the Clark National Forest. Data are presented as a percent of peak class. See page 2.

This observed secondary fire peak corresponds in time to the Wildland Fire Danger Rating System's prediction of maximum fire danger to occur during September. However, observed fire activity on the Clark National Forest was much greater during the spring and fall fire seasons than it was during this September anomalous period.

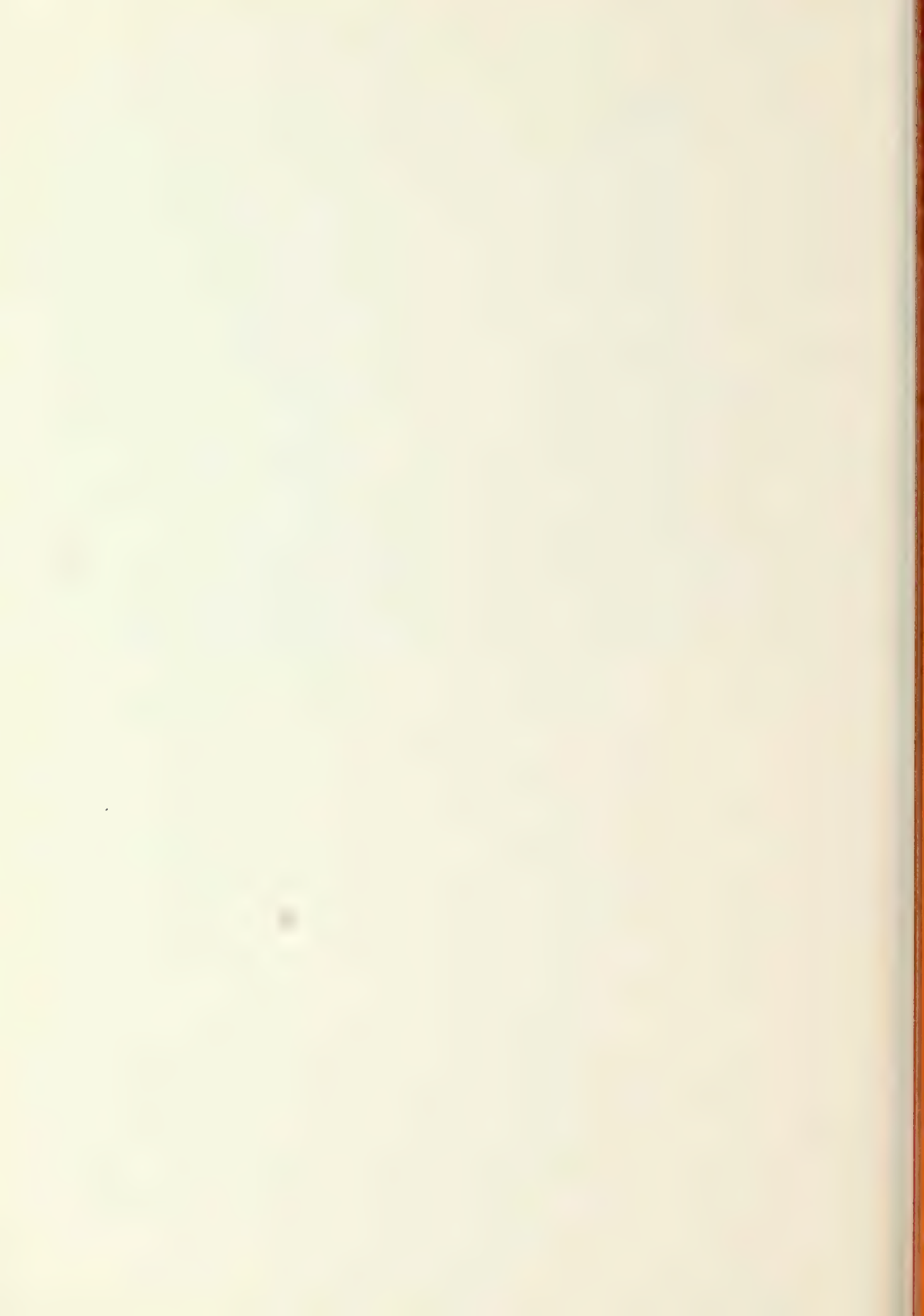
Therefore, this is an example of one use where the accuracy of predictions derived from the Wildland Fire Danger Rating System might be challenged. In Missouri, the System is lacking because it doesn't employ a hardwood fuel model. The foliage of oak-hickory forests and herbaceous vegetation both influence the fire potential. Although solar radiation during March and April is almost equal to that during August and September, the measured radiation on

forest floors is 20 percent less during March and April because there are more cloudy days during the spring. Despite this, the fire potential is greater during the spring season because the leafless condition of the trees permits more of the available solar radiation to filter through to the litter and slash. Also in the spring the quantity of fuels is at its peak because the oaks have completely shed their dead foliage.

Moreover the Wildland Fire Danger Rating System fails to provide for seasonal variability of man-caused risks, which are key factors in Missouri where incendiary and debris-burning are the known leading causes of fire. The risk from such fires are extremely high in the spring. Den-tree fires by hunters pose a major risk in the fall.

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1975. Wildfire atlas of the northeastern and north central States. USDA For. Serv. Gen. Tech. Rep. NC-16, 25 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Describes patterns of forest fire activity across the northeastern and north central United States. Gives average dates of greening and curing of herbaceous plants, median size of fires in various fuels, and annual profiles of peak fire activity. It also examines combinations of major fire cause and day-of-week activity.

OXFORD: 431.1:431.3:435.2(084.4)(74/77). KEY WORDS: fire danger rating, herbaceous stage, fire season, national forests.

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